AD-A058 782 ARCTEC INC COLUMBIA MD F/G 13/2
SYSTEMS FOR ARCTIC SPILL RESPONSE. VOLUME I.(U)
MAR 78 L A SCHULTZ, P C DESLAURIERS DOT-CG-71343-A
UNCLASSIFIED 405C-3-VOL-1 USCG-D-44-78-VOL-1 NL

1 OF 4
AD
A058 782

18 USCG

LEVEL III

12

Report No. 19 CG-D-44-78-VOL-1

6 SYSTEMS FOR ARCTIC SPILL RESPONSE. Volume I.

10 L. A. Schultz, P. C. Deslauriers, F. W. DeBord, R. P. Voelker

ARCTEC, Incorporated
9104 Red Branch Road
Columbia, Maryland 21045

14 405C-3-VOL-1

12 327p.

11 Marc[redacted]978

9 FINAL REPORT. Aug 77-Mar 78,

Volume I

Document is available to the U. S. public through the
National Technical Information Service
Springfield, VA 22161

Prepared for

U. S. Department of Transportation
United States Coast Guard
Office of Research and Development
Washington, D. C. 20590

15 DOT-CG-71343-A

407 822

78 09 05 235

NOTICE

The United States Government does not endorse products or manufacturers. Trade or manufacturer's names appear herein solely because they are considered essential to the object of this report.

Technical Report Documentation Page

1. Report No. CG-D-44-78	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Systems For Arctic Spill Response VOL. 2 AO58783		5. Report Date March 1978
		6. Performing Organization Code
7. Author(s) L.A. Schultz, P.C. Deslauriers, F.W. DeBord, R.P. Voelker		8. Performing Organization Report No. 405C-3
9. Performing Organization Name and Address ARCTEC, Incorporated 9104 Red Branch Road Columbia, Maryland 21045		10. Work Unit No.
		11. Contract or Grant No. DOT-CG-71343-A
12. Sponsoring Agency Name and Address Department of Transportation United States Coast Guard Office of Research and Development Washington, D. C. 20590		13. Type of Report and Period Covered Final Report August 1977-March 1978
		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

This final report summarizes the work accomplished under the program entitled "Study to Define Arctic Pollution Response Systems and Develop Arctic Oil Pollution Response Project Plans." The objective of the program was to determine the most cost effective, environmentally compatible, and technically feasible Coast Guard arctic pollution response system that can be used in projected oil spill scenarios to recover and dispose of spilled oil. The optimum arctic pollution response system was determined by establishing the cost and effectiveness of response for sixteen oil spill response situations, and developing six alternative Coast Guard arctic pollution response systems based on these situations. These six systems were developed with a recognition of three distinctly different types of operational requirements, those for thick stable ice, dynamic hummocky ice, and open water or light ice conditions. The optimum system was then identified as the result of a cost effectiveness analysis. The six arctic oil spill scenarios consisted of a gathering pipeline rupture in the nearshore Beaufort Sea, an oil well blowout from a very large reservoir in the nearshore Chukchi Sea, crude oil tanker casualties in Norton Sound and in the Navarin Basin region of the Bering Sea, an oil well blowout from an average sized reservoir in Bristol Bay, and a fuel oil spill resulting from the collision of a fuel oil barge in Unimak Pass. The optimum system provides for a 25% response level for the Norton Sound, Navarin Basin, Bristol Bay, and Unimak Pass scenarios, and a 50% response level for the Beaufort Sea and Chukchi Sea scenarios. Modifications in the optimum system required to extend its capability to subarctic applications in the lower 48 states were also identified.

17. Key Words Oil Spills, Oil Pollution, Oil Spill Scenarios, Alaskan Pollution, Arctic Pollution, Oil Spills in Ice Covered Waters	18. Distribution Statement

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	328	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

78 09 05 238

PREFACE

The cooperation, support, and technical contributions of LT Gordon D. Marsh, the U. S. Coast Guard's Technical Representative for the program, is gratefully acknowledged.

Significant contributions to the project were also made under subcontract by the University of Alaska's Environmental Information and Data Center (AEIDC), Crowley Environmental Services Corporation of Anchorage, Alaska, and McAllister Pollution Controls, Limited of Montreal, Canada. The analysis of the ecological sensitivity of Alaskan coastal and offshore areas was performed by Dr. Eugene H. Buck of AEIDC. Crowley Environmental Services Corporation was responsible for the assembly of the inventory of on-scene Alaskan oil spill response equipment, and contributed in a major way to the development of realistic oil spill response scenarios based upon their operating experience in Alaskan oil spill response operations. Crowley also made significant contributions in establishing the cost of spill response efforts. While several Crowley staff members were involved in this work, special appreciation is extended to Alan A. Allen and Sharon Jeane. The staff of McAllister Pollution Controls, Limited also reviewed the proposed oil spill response scenarios for realism based upon their operating experience in responding to oil spilled in Canadian ice infested waters.

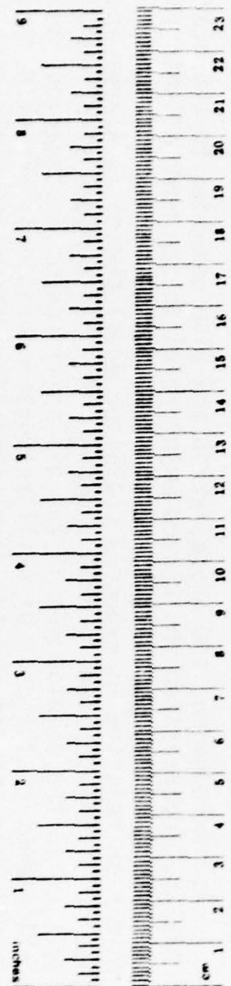
Acknowledgement and appreciation are also extended to the staff members of ARCTEC, Incorporated who played major roles in the work of this program. Paul C. Deslauriers was largely responsible for gathering and summarizing information relative to expected petroleum developments in Alaska and the behavior of oil spilled in cold regions. Mr. Deslauriers also led the effort resulting in the development of the oil spill response scenarios, and the establishment of the cost of spill response operations. Frank W. DeBord was primarily responsible for the development of methods for evaluating the effectiveness of an oil spill response system, the development of the procedures for selecting the preferred arctic oil spill response system, and for much of the work associated with the subarctic portions of the program. Richard P. Voelker was responsible for developing the summary of environmental conditions for both the arctic and subarctic areas, and the development of the subarctic oil spill scenarios. Mr. Voelker also contributed to the development of oil spill response scenarios for both the arctic and subarctic cases.

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

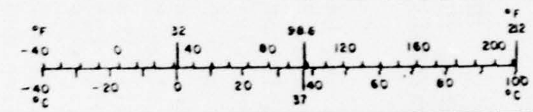


TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

LIST OF TABLES

LIST OF TABLES (Continued)

LIST OF TABLES (Continued)

LIST OF TABLES (Continued)

LIST OF TABLES (Continued)

LIST OF TABLES (Continued)

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

SUMMARY

This final report summarizes the work accomplished in Phase I of the program entitled "Study to Define Arctic Pollution Response Systems and Develop Arctic Oil Pollution Response Project Plans." The overall objective of the program is to prepare a plan for the development by early next decade of an optimum Coast Guard arctic pollution response system. The program was formulated in terms of two phases. The objective of the first phase of the study was to determine the optimum arctic oil pollution response system package through the application of cost effectiveness analysis techniques to selected oil spill response scenarios. The objective of the second phase of the study is to prepare detailed technical and management plans for each system and subsystem comprising the optimum oil spill response system package. This report summarizes the work performed in Phase I of the program.

Alternative arctic pollution response systems were developed on the basis of projected responses to six Alaskan oil spill scenarios which were selected so as to encompass the majority of spill and environmental conditions likely to be encountered in coastal and offshore Alaska. These six oil spill scenarios consist of the rupture of a sub-sea gathering pipeline in the nearshore Beaufort Sea, an oil well blowout from a very large reservoir in the nearshore Chukchi Sea, crude oil tanker casualties in Norton Sound and in the Navarin Basin region of the Bering Sea, an oil well blowout from an average sized reservoir in Bristol Bay, and a fuel oil spill resulting from the collision of a fuel oil barge in Unimak Pass. Oil spill response scenarios were developed for each spill scenario for three levels of response capability, 25, 50, and 80 percent, for all but the Unimak Pass spill scenario, and for a single level of response of 25% for the Unimak Pass scenario. The manpower and equipment associated with these sixteen spill response scenarios formed the basis for the development of the alternative arctic oil spill response systems.

The alternative arctic oil spill response systems were evaluated on the basis of a cost effectiveness analysis. The costs associated with each level of response capability for each of the six oil spill scenarios were estimated in detail. All costs, including costs associated with equipment to be developed in the future, were converted into a usage rate or rental rate form. These usage costs incorporate all cost components including development, procurement, maintenance, staging, and operational costs. For the purposes of this program, it was determined that the effectiveness of an oil spill response system should be based on a comparison of the impact the spill would have on the environment with no response to the impact the spill would have with a given level of response. Also, for the purposes of this program, impact was defined as the summation over a time period of the product of the volume of the spill remaining, the areal coverage of the spill, and the relative ecological sensitivity of the region. The cost and effectiveness of each of the sixteen spill response efforts were then normalized on the basis of the total cost for the maximum response capability, and the corresponding effectiveness of the maximum response, respectively. These values of normalized cost and effectiveness were then used to determine the cost effectiveness

index for each of the sixteen response efforts. Alternative arctic spill response systems were then developed on a cost effectiveness basis after grouping common spill response situations and techniques. These groupings can be briefly catagorized as those for thick, stable, level ice conditions; those for dynamic, hummocky ice conditions; and those for open water and light ice conditions. Six alternative systems were defined having a range in response capability extending from a minimum response level of 25% for all six scenarios to a maximum response level for all scenarios, defined as 80% response for all but the Unimak Pass scenario and 25% response for the Unimak Pass scenario. The optimum system, as defined by the cost effectiveness analysis, results in the capability to respond at the 25% level to the Norton Sound, Navarin Basin, Bristol Bay, and Unimak Pass scenarios, and at the 50% level to the Beaufort Sea and Chukchi Sea scenarios. In terms of response groups, this capability corresponds to a 50% response for thick, stable, level ice conditions, and a 25% response for the remaining conditions.

While the primary emphasis of this program was placed on the coastal and offshore regions of Alaska, it was recognized that the approaches developed for oil spill response in offshore Alaska may be applicable to some degree in other subarctic ice infested waters of the lower 48 states. The program, therefore, included the evaluation of the alternative Coast Guard arctic oil spill response systems for application in seasonally ice infested waters of the lower 48 states. The approach used in the development of subarctic system requirements closely paralleled the approach used for the arctic cases, with the study based upon selected oil spill scenarios. Three representative subarctic oil spills in ice infested waters were selected consisting of a Great Lakes oil spill resulting in the release of No. 6 residual fuel oil from a tanker grounding at Johnson's Point Turn in the St. Marys River, a northern rivers scenario consisting of a release of No. 6 residual fuel oil in the Hudson River at a turn near West Point due to the grounding of a barge, and a northern coastal area scenario resulting in the release of No. 2 fuel oil from a barge grounding at Cleveland Ledge in Buzzards Bay, Massachusetts. Oil spill response scenarios were developed for three levels of response capability for the three subarctic oil spill scenarios, and the equipment associated with these nine additional spill response scenarios was identified. The modifications required in the arctic pollution response system to include an intermediate level of response capability in the subarctic scenarios, ranging from 45 to 50% response, were then identified.

As a result of this study, it was determined that the presence of ice sometimes helps and sometimes hinders the spill response effort. On the basis of the spill response scenarios developed in this program, there appears to be a substantial amount of spill response capability based on current technology and currently available equipment. Some additional equipment needs to be developed, however, and the suitability of the proposed techniques must be demonstrated in most cases through laboratory and field test programs. The type of oil involved in the spill, and the environmental conditions surrounding the spill situation, result in the establishment of practical limitations to the level of response capability which can be achieved. The most cost effective response levels were found to be the lower to intermediate response

levels. In several cases, a high response level of 80% required the use of a special oil/ice recovery vessel which has the capability of recovering and cleaning oil contaminated ice in addition to recovering the oil left in an open water condition after removal of the ice. The special oil/ice recovery vessel, which does not exist at the present time, was, however, shown to be non cost effective. The optimum arctic pollution response system is basically a combination of equipment lists developed for the various spill scenario/ response level combinations, with appropriate adjustments made for commonality. No single approach applies universally to all arctic oil spill scenarios, therefore, there is no piece of universally applicable oil spill response equipment. In a similar manner, the spill situations addressed by the sub-arctic spill scenarios are, in turn, distinct from the arctic scenarios, and are distinct from each other; therefore, a combination of equipment is again required to achieve the desired response capability for subarctic ice infested waters.

It is recommended that the Coast Guard proceed as planned towards developing a complete arctic pollution response system by early next decade. The next step in this process consists of the development of detailed research and development plans directed towards establishing new equipment where required, evaluating alternative equipment choices where such exists, and demonstrating through laboratory and field test programs the applicability of the spill response techniques proposed. It is also recommended that consideration be given to establishing an independent spill response system for use in subarctic ice infested waters since the commonality of equipment required for the subarctic and arctic response efforts is relatively limited, and since it is likely that it would be more desirable to store the subarctic system in a ready condition in close proximity to the Great Lakes, northern rivers, and northern coastal regions, rather than in Anchorage or Kodiak where the arctic spill response system will likely be stored and maintained.

INTRODUCTION

Continuing predictions of world oil and natural gas shortages indicate that both the petroleum reserves already discovered in the world arctic region and those expected to be discovered will be developed in a timely manner. This increased petroleum industry activity related to the exploration, development, production and transportation of Alaskan oil and gas will increase the potential for oil pollution in cold regions.

By authority granted through the Federal Water Pollution Control Act, the U.S. Coast Guard has the responsibility for preventing and controlling oil spills in and along the coastal waters of the United States. Included in the areas of responsibility are the arctic and subarctic coastal waters of Alaska, and other subarctic seasonally ice infested waters such as the waters of the Great Lakes, the northern rivers and northeastern coastal areas. In order to better understand the priority and practicality of responding to arctic oil spills, the U.S. Coast Guard has conducted numerous studies and field tests which served to further define the problem and to evaluate the level of current capability in responding to cold regions oil spills. This work, in combination with other research efforts related to cold regions, such as the Canadian Beaufort Sea Project, sponsored jointly by the Canadian petroleum industry and the Canadian government, and the U.S. Bureau of Land Management's Alaskan Outer Continental Shelf Environmental Assessment Program, has resulted in the development of sufficient information and experience so as to allow the formulation of research and development plans for the development of an arctic pollution response system suitable for application in ice infested waters. The contract under which the work reported herein was completed will ultimately result in the formulation of these research and development plans.

The overall objective of this program was to prepare a plan for the development of an optimum Coast Guard arctic pollution response system by early next decade. This research program was formulated in terms of two phases. The objective of the first phase of the study was to determine the optimum arctic oil pollution response system package through the application of cost effectiveness analysis techniques to selected oil spill scenarios. The objective of the second phase of the study was to prepare detailed technical and management plans for each system and subsystem comprising the optimum oil spill response system package. The general approach to the program initially consisted of a literature search directed towards gathering all available information bearing on the problem of arctic oil spill response systems augmented by personal communications with the major researchers active in this field of research. Following the gathering, review, analysis and synthesis of all available information, the study becomes one of systems analysis whereby system and subsystem goals and performance criteria for selected spill scenarios are developed and compared with existing capabilities. Once the system requirements have been defined, the optimum system is identified as the result of a cost effectiveness analysis. The optimum system selected on the basis of arctic applications is also compared to subsystem requirements developed for the subarctic ice infested waters of the Great Lakes, the northern rivers, and the northeastern coastal areas. The final portion of the program then consists of the development

of arctic pollution response project plans for the selected optimum U. S. Coast Guard arctic pollution response system.

The first phase of this research program has been divided into six major tasks. The objective of the first task was to critically review the seven oil spill scenarios outlined by the U.S. Coast Guard for consideration, determine their adequacy, revise the scenario listing as required, and select the six arctic oil spill scenarios to be used as the basis for all work in the remainder of the program. The geographic area of primary concern to the arctic portion of this study consists of the coastal and offshore areas of Alaska as shown in Figure 1. Key cities and offshore areas of significance to the oil spill problem are identified in the figure. The six representative oil spill scenarios selected in Task 1 to encompass the majority of spill and environmental conditions likely to be encountered in offshore Alaska were then analyzed in Task 2 with the objective of developing a preferred oil spill response scenario for each of the six oil spill scenarios for three levels of response capability, initially indentified as 25, 50 and 90% response. The work of Task 2 included the development of preferred oil spill response scenarios, the establishment of system and subsystem goals and performance criteria for each functional area of each scenario, the comparison of existing capability with these performance requirements, and the development of complete oil spill response systems on the basis of both existing and newly developed equipment and techniques. The functional areas of oil spill response were identified as detection, surveillance, containment, recovery, temporary storage, transfer, disposal, ancillary, emergency evacuation and logistics. Shoreline cleanup and restoration were not included as functional areas of oil spill response in this study. Equipment and manpower requirements were then identified for the application of each oil spill response system to its oil spill scenario. With the completion of the development of preferred spill response scenarios for each of the spill/response level combinations in Task 2, the work of Task 3 consisted of the development of the specific spill response oriented systems into a more generalized arctic spill response system. Six candidate systems were identified in the course of the work of Task 3, and an optimum system was selected on the basis of a cost effectiveness analysis. The objective of Task 4 of the program was to evaluate the alternative Coast Guard arctic oil spill response systems developed in Task 3 for application in subarctic seasonally ice infested waters such as those found in the Great Lakes, the northern rivers, and the northeastern coastal areas. This evaluation followed a procedure similar to that developed for the arctic systems, consisting initially of the development of oil spill scenarios for the three subarctic applications, the development of alternative and preferred spill response scenarios with the definition of system and subsystem performance criteria for three levels of spill response capability, and the comparison of the performance capability of the alternative Coast Guard arctic spill response systems with the performance criteria required for the subarctic applications. Subsystem inadequacies and excesses were then identified, and the modifications required in the optimum Coast Guard arctic spill response system to adapt it for application to oil spilled in the subarctic regions were then identified. The final two tasks of the Phase 1 effort consisted of the preparation of an executive briefing package and the Phase 1 final report. The Phase 2 effort consists of the development of detailed project plans for the U.S. Coast Guard's arctic pollution response system.

Figure 1. Map of Alaska Identifying Key Cities and Offshore Regions of Significance to the Oil Spill Problem

The work reported herein was performed in the time period spanning August 1977 to March 1978. The factual data upon which this study was based was the most recent data available at the time the work was performed. The projections of future events upon which the study is based have been developed on the basis of their being reasonable and representative as related to the objectives of this program. While these projections of future events could be subjected to a great deal of debate, and an infinite array of variations could be proposed and justified based upon the current state of knowledge of all factors, the effect of these variations on the results of this study should be minor if all variations result in an equally representative projection of future events. This study was performed with a full realization of the possible broad variations in the development of future events, but with a focus on the selection of representative projections based on the state of knowledge at the time the work was performed. All cost figures contained in this report are in terms of early 1978 dollars.

The work completed under Phase 1 of this program is described in detail in the following sections of this report. The next section of the report is a summary of the procedure used for selecting the representative arctic oil spill scenarios upon which the remainder of the work is based. Six representative arctic oil spill scenarios result from this analysis. In the next section of the report oil spill response scenarios are developed for each of the six spill scenarios for three levels of oil spill response capability. Following the identification of the preferred oil spill response scenarios, the cost of spill response and the effectiveness of spill response are determined. These factors are then combined in the development of six alternative arctic spill response systems, and an optimum system is identified on the basis of a cost effectiveness analysis. Following the selection of the optimum arctic spill response system, the following two sections of the report are concerned with the adaptation of the arctic system to subarctic applications, with the selection of subarctic spill scenarios, the development of subarctic spill response scenarios, and the evaluation of the alternative arctic systems for use in subarctic applications. The conclusions and recommendations resulting from the work of this program are then presented in summary form.

SELECTION OF ARCTIC OIL SPILL SCENARIOS

The development of an arctic pollution response system in this study was to be based on six arctic oil spill scenarios. These scenarios were to be selected as being representative of the range of environmental conditions and oil spill conditions likely to be encountered in the coastal and offshore regions of Alaska. The U. S. Coast Guard offered seven potential oil spill scenarios for consideration in this study based upon the results of previously completed research programs.

The procedure for selecting the six representative arctic oil spill scenarios began with a broad review of all prior work related to the development of such scenarios for both the U. S. and Canadian arctic. This prior work included two studies performed for the U. S. Coast Guard, work related to an offshore oil well blowout in the Canadian Beaufort Sea Project, and work associated with hypothetical spills developed for the BLM/NOAA Outer Continental Shelf Environmental Assessment Program. All of the previously developed oil spill scenarios were then reviewed in conjunction with a broad overview of oil spill scenario factors which included oil spill potential, environmental conditions, and ecological sensitivity.

In determining the oil spill potential of Alaska, a search was undertaken for the latest information available on known and projected Alaskan petroleum reserves, state and federal government lease sale plans, and industry plans for the development of these petroleum resources. Various spill types were also identified by defining the type of oil, the volume of oil released, the rate at which the oil is released, and the likely transport of the spilled oil. The most recent information available on coastal and offshore Alaskan environmental conditions was also reviewed and summarized. These environmental conditions included ice, air temperature, water depths, water currents, waves, tides, water temperature, daylight, precipitation, visibility, earthquakes, winds, and storms. A final consideration in the broad overview of Alaskan oil spill potential consisted of the development of a relative ranking of the ecological sensitivity of Alaska's coastal and offshore regions.

An analysis of all of these factors then resulted in the selection of six oil spill scenarios which were judged to encompass the majority of spill and environmental conditions likely to be encountered in coastal and offshore Alaska. The selected oil spill scenarios were then informally reviewed with representatives of the petroleum industry to guarantee their appropriateness for use as the foundation for this study. The industry representatives concurred with the results of the analysis.

Spill Scenario Background

Two prior studies sponsored by the U.S. Coast Guard provide valuable background information for the selection of Alaskan oil spill scenarios. The first of these studies, completed by the Pacific Northwest Laboratories of Battelle Memorial Institute in February of 1974 [1], was directed toward the determination of the oil spill potential associated with future Alaskan oil production and transportation systems. This study was based upon the best information available at that time regarding the occurrence and possible production of oil in Alaska, petroleum demand considerations relating to future Alaskan oil production, the institutional and technological framework for development of oil production and transportation systems, arctic crude oil transportation systems, environmental conditions, and the behavior of crude oil spilled under arctic conditions. This study resulted in the definition of oil spill scenarios in varying degrees of detail for ten geographic locations in Alaska. These spill scenarios are briefly summarized in Table 1. The greater completeness of the spill scenarios identified for Port Valdez, lower Cook Inlet and the Gulf of Alaska was justified on the investigator's ability to predict future events with some acceptable degree of confidence at the time of the study. The remaining geographic locations for which spill type and spill volume are relatively undefined were felt to be so dependent upon future developments that meaningful estimates could not be made at the time of the study. The remaining geographic areas, identified as areas for potential oil spills in the future, included Bristol Bay, Kuskokwim Bay, the Bering Sea Shelf, Norton Sound, the Beaufort Sea, the Chukchi Sea, Kotzebue Sound and the Unimak Pass area.

The second study relating to the selection of Alaskan oil spill scenarios was completed for the U.S. Coast Guard in June of 1975 by Mathematical Sciences Northwest, Incorporated. This work, reported in two volumes [2], resulted in a ranking of potential environmental impact for spills of crude oil, No. 2 diesel fuel, bunker C fuel, and gasoline in varying amounts ranging from 100 to 50,000 barrels for specific sites at Yakutat Bay, Valdez Harbor, Valdez Narrows, the Drift River Channel, Port Graham, Kamishak Bay, Unimak Pass, Port Moller, Kvichak Bay, St. Matthew Island, offshore Prudhoe, onshore Prudhoe, Nome, Cape Blossom Channel, the Colville River, the Yukon River and Denali Fault. The range of spill volume selected was intended to cover spill situations including a tanker casualty, a drilling rig discharge, a release associated with a tanker transfer operation, an uncontrolled tanker ballast discharge, a pipeline failure, a refined product barge casualty and miscellaneous spills. Individual cases examined for natural oil dispersion numbered 372, and an additional 22 cases were analyzed for the case where oil spill cleanup was assumed to take place. The results of this study are briefly summarized in incomplete form in Table 2 where the top 25 no cleanup cases and all 22 cleanup cases are summarized. For both the cleanup and no cleanup cases, the greatest environmental impact was estimated to occur as a result of a spill of 50,000 barrels of No. 2 diesel oil in the summer at Port Graham. It is seen that for the no cleanup situation the greatest environmental impact was estimated to occur in southern Alaska for all but one case, that exception being a large spill of crude at a pipeline crossing the Yukon River. It is also significant that 21 of the

TABLE 1. SPILL SCENARIOS DEVELOPED IN THE BATTELLE - NORTHWEST STUDY [1]

Geographic Location	Spill Type	Spill Volume
Port Valdez	Tanker ballast discharge	50 to 900 bbl/incident
	Oil transfer at terminal	5,000 bbl max, 129 bbl avg
	Tanker casualty	70,000 bbl
	Miscellaneous (not crude)	100 to 500 bbl
Lower Cook Inlet	Well blowout	1,000 bbl max
	Tanker ballast discharge	50 to 500 bbl/incident
	Oil transfer operations	1,000 bbl max, 150 bbl avg
	Tanker casualty	60,000 bbl
	Miscellaneous (not crude)	100 to 500 bbl
Gulf of Alaska	Well blowout	1,000 bbl max
	Pipeline rupture	5,000 bbl max
	Tanker ballast discharge	50 to 500 bbl
	Oil transfer operations	1,000 bbl max
	Tanker casualty	40,000 to 60,000 bbl
Bristal Bay and Kuskokwim Bay	-	Premature, rough estimate by doubling Cook Inlet figures
Bering Sea Shelf	-	-
Norton Sound	-	Premature, rough estimate by 2 to 3 x Cook Inlet figures
Beaufort Sea	-	-
Chukchi Sea	-	-
Kotzebue Sound	-	-
Unimak Pass	-	-

TABLE 2. RANK ORDER OF ENVIRONMENTAL IMPACT FOR NO CLEANUP AND CLEANUP CASES AS DEVELOPED IN THE MSNW STUDY [2]

RANK	NO CLEANUP				CLEANUP			
	Location	Season	Spill Type	Spill Vol.(bbl)	Location	Season	Spill Type	Spill Vol.(bbl)
1	Port Graham	Summer	Diesel	50,000	Port Graham	Summer	Diesel	50,000
2	Port Graham	Summer	Diesel	10,000	Valdez Narrows	Summer	Diesel	50,000
3	Valdez Narrows	Summer	Diesel	50,000	Valdez Narrows	Summer	Crude	50,000
4	Valdez Narrows	Summer	Diesel	10,000	Drift River	Summer	Diesel	50,000
5	Valdez Narrows	Summer	Crude	50,000	Port Graham	Summer	Crude	50,000
6	Port Graham	Summer	Crude	50,000	Yukon River	Summer	Crude	50,000
7	Drift River	Summer	Diesel	50,000	Drift River	Summer	Crude	50,000
8	Unimak	Summer	Diesel	50,000	Unimak	Summer	Diesel	50,000
9	Yukon River	Summer	Crude	50,000	Valdez Narrows	Summer	Bunker C	50,000
10	Drift River	Summer	Crude	50,000	Port Moller	Summer	Diesel	10,000
11	Unimak	Summer	Crude	50,000	Yakutat	Summer	Diesel	50,000
12	Valdez Narrows	Winter	Crude	50,000	Onshore Prudhoe	Summer	Crude	50,000
13	Valdez Narrows	Winter	Diesel	50,000	Kamishak	Summer	Diesel	1,000
14	Valdez Narrows	Summer	Bunker C	50,000	Kvichak	Summer	Diesel	10,000
15	Valdez Narrows	Summer	Crude	10,000	Nome	Summer	Crude	50,000
16	Port Graham	Summer	Bunker C	50,000	Cape Blossom	Summer	Crude	50,000
17	Drift River	Summer	Diesel	10,000	Desali Fault	Summer	Crude	10,000
18	Port Graham	Summer	Crude	10,000	Valdez Harbor	Summer	Crude	1,000
19	Valdez Narrows	Winter	Diesel	10,000	Umiat	Summer	Crude	10,000
20	Unimak	Summer	Diesel	10,000	Offshore Prudhoe	Summer	Crude	50,000
21	Valdez Narrows	Winter	Bunker C	50,000	St. Matthew	Summer	Diesel	10,000
22	Yakutat	Summer	Diesel	50,000	Port Graham	Summer	Gasoline	50,000
23	Drift River	Summer	Bunker C	50,000				
24	Valdez Narrows	Summer	Bunker C	10,000				
25	Port Graham	Summer	Bunker C	10,000				

top 25 cases for the no cleanup situation occurred in the summer with only 4 occurring in winter, while for the cleanup situation all 22 cases occurred in summer. Interpreting the results of the Mathematical Sciences Northwest study in very broad form according to geographic location for both the no cleanup situation and the cleanup situation, the geographic areas at which the greatest environmental impact was estimated to occur are shown in Figure 2, with the number indicating the ranking of that geographical area for potential environmental impact due to oil spills.

Perhaps the most famous Arctic oil spill scenario is that which was developed for use in the Canadian Beaufort Sea Project, a multi-million dollar regional environmental assessment program jointly funded by the Canadian government and the Canadian petroleum industry. For a seabed blowout in water depths of 50 to 600 feet, the blowout scenario selected consisted of an initial flow of 2,500 barrels per day decreasing linearly with time over a 30 day period to a rate of 1,000 barrels per day, at which rate it continues indefinitely. The oil is assumed to be saturated with gas when it leaves the reservoir. This gas comes out of solution as the pressure is released and expands so that at the surface it occupies a volume of 800 cubic feet per barrel of oil. The temperature of the oil was assumed to be 185°F. While the original scenario, which had a sustained blowout rate of 1,500 barrels per day rather than the final number of 1,000 barrels per day, is documented [3], the rationale behind the selection of the blowout rates has never been documented. The limited additional information that is available indicates that the blowout scenario selected for the Canadian Beaufort Sea Project was developed in an informal meeting between industry and government representatives based upon industry's experience operating in similar geological formations. As related to the selection of the Canadian Beaufort Sea blowout rate, the major geological consideration is the fact that the region is a river delta of relatively young geological age and relatively shallow depth. The geological characteristics of the area selected for the Canadian Beaufort Sea study are quite different from those of the offshore Prudhoe Bay region, for example, which is of much earlier formation.

The seven oil spill scenarios selected by the U.S. Coast Guard for preliminary consideration and review in this study are summarized in Table 3. The lower Cook Inlet (Port Graham) site, had the highest impact score for a spill of 50,000 barrels of No. 2 diesel oil in the summer in the MSNW study. This scenario was apparently changed from a summer to a winter spill in order to change the spill situation from an open water situation to that of a broken ice field. The Unimak Pass scenario was selected on the basis of this location being on the major shipping route through the Aleutian Islands. While the spill situation is one of open water, this location is typically characterized by overcast, windy and stormy conditions. Umiat was selected as a tundra spill site because of its location along the Coleville River in the region known as the National Petroleum Reserve in Alaska (NPRA). The summer spill of 50,000 barrels of crude oil offshore Prudhoe Bay presents a case of oil spill recovery with oil located on and under ice. The 10,000 barrel spill of diesel oil in winter offshore Nome comprises the fast ice oil spill scenario. The Valdez Narrows spill scenario covers the case of a large release of diesel oil in open water conditions. The final suggested scenario is that for the

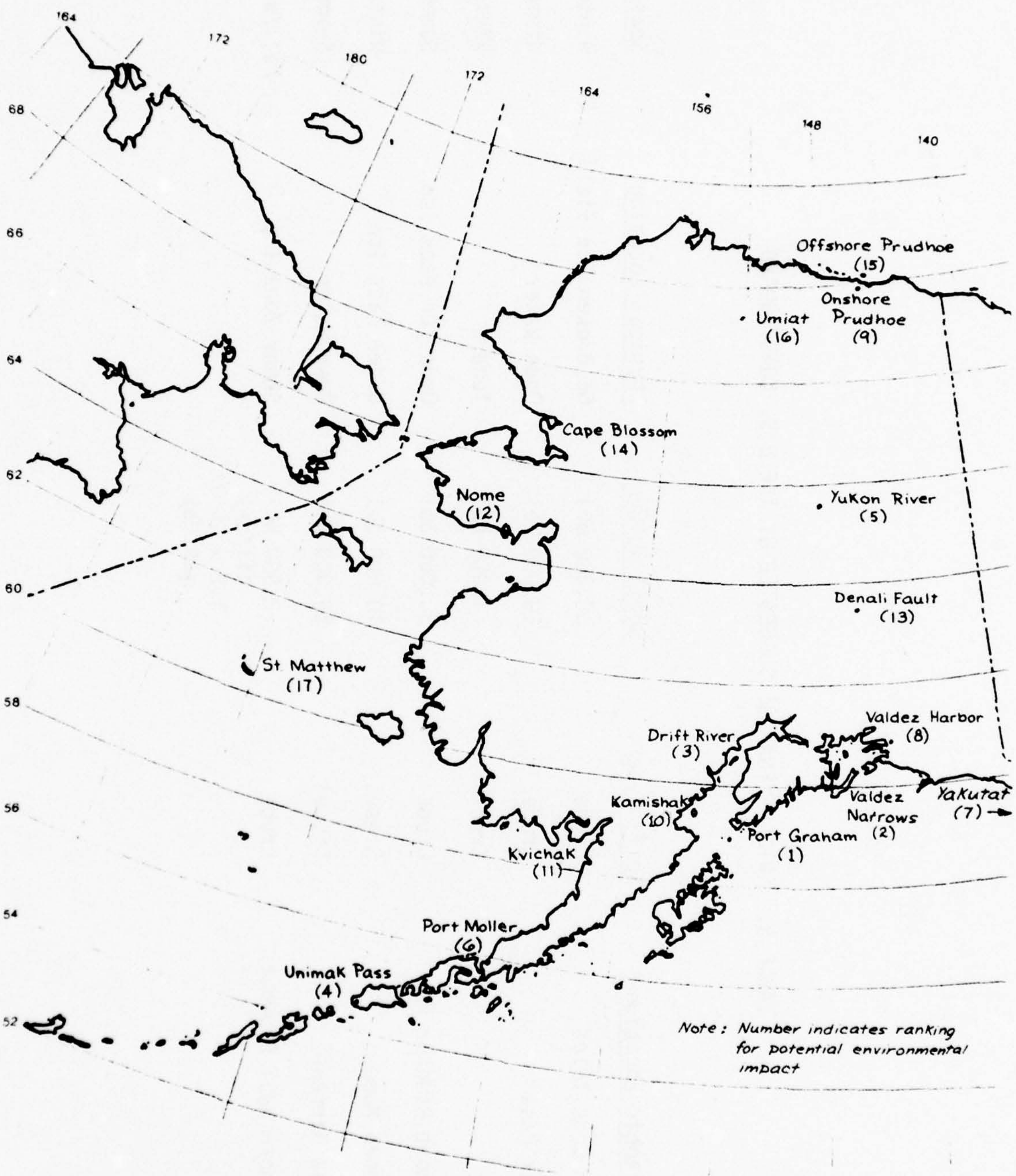


Figure 2. Alaskan Oil Spill Locations Selected for the MSNW Study

TABLE 3. SPILL SCENARIOS SUGGESTED BY THE U.S. COAST GUARD

Geographic Location	Spill Type	Spill Volume	Physical Location	Season
Lower Cook Inlet	Crude	50,000 bbl	On Broken Ice Field	Winter
Unimak Pass	Crude	10,000 bbl	Open Water	Winter
Umiat	Crude	1,000 bbl	Tundra	Winter
Offshore Prudhoe Bay	Crude	50,000 bbl	Under/On Pack Ice	Summer
Offshore Nome	Diesel	10,000 bbl	Under Fast Ice	Winter
Valdez Narrows	Diesel	50,000 bbl	Open Water	Summer
Offshore Well Blowout	Crude	2,500 bbl oil/day; $1.2 \times 10^5 ft^3$ gas/day	Shear Zone Ice	Fall/Winter

offshore oil well blowout which was taken directly from the Canadian Beaufort Sea study. This scenario is located in the most severe ice conditions possible, those of the shear zone.

Another major Arctic environmental assessment program is the U.S. Bureau of Land Management - National Oceanic and Atmospheric Administration Outer Continental Shelf Environmental Assessment Program (OCSEAP). The proceedings of a synthesis meeting of OCSEAP investigators held at Barrow, Alaska in early February of 1977 was issued under the title "Draft Beaufort Sea Synthesis Report" as Special Bulletin No. 15, dated 1 June 1977 [4]. As reported in this document, the interdisciplinary group concerned with spills, transport, and effects of oil constructed two hypothetical spills. The first spill was constructed as an instantaneous release of 10^6 gallons (approximately 24,000 barrels) of crude oil inside the Barrier Islands during an ice free period in summer. The second spill was also an instantaneous release of the same size but occurring in early January beneath fast ice. In both cases, the water depth was assummed to be 6 meters, corresponding to a location between Prudhoe Bay and Cross Island. Two of the artificial assumptions recognized by the group was that the spills were assummed to be instantaneous and that the release consisted only of oil rather than a gas/oil mixture. The interdisciplinary group concerned with biota and habitats also briefly addressed oil spill events in general terms. This group selected three occurrences upon which to base their likely sequence of events following controlled or accidental OCS impacts. The three occurrences included the occurrence of a significant oil spill, the establishment of a camp-type settlement, and chronic releases of relatively small volumes of fuel oil and gasoline into the Beaufort Sea system. For the first case of a significant oil spill, the group selected an oil well blowout in 10 meters of water at Harrison Bay, Alaska caused by the shift of a drilling platform. The group further assummed that two million gallons (48,000 barrels) of crude oil are released over a seven day period after which the blowout is arrested. The environmental impact associated with the second occurrence, the establishment of a year-round construction camp, was not oil spill related. For the third occurrence of continuous losses of fuel products associated with transit and transfer, a scenario was developed involving a settlement on the mainland, a causeway to the Barrier Islands and the drill sites, and the drill sites themselves, possibly incorporating production wells. The specific oil spill events identified included a 50 gallon spill every two weeks at Pingok Island, a 50 gallon spill every two weeks at Oliktok, a 2,000 gallon spill every two months from the causeway, and a 2,000 gallon spill every two months at Thetis Island.

Informal discussions related to offshore petroleum development along the Alaskan Beaufort Sea coast have been held with U.S. oil industry representatives. Well blowouts from either exploration or production operations were judged to vary with field size from 50,000 barrels per day for a very large field to 5,000 barrels per day for an average size field. These oil blowouts would be expected to be accompanied by 700 to 800 scf of gas per barrel of oil. It was also judged that a period of 30 to 45 days would be required to kill the blowout by drilling a relief well. For a catastrophic failure of a crude oil pipeline, the release is expected to be relatively small due to the capability to shut in production within minutes through the use of check valves

in the line. Alyeska has designed the TAPS pipeline such that the largest volume to be spilled due to a catastrophic line failure would be 50,000 barrels of oil. Considering the fact that gathering lines to offshore structures would be much smaller and shorter, the release from a buried offshore pipeline would be expected to be considerably less than this 50,000 barrel figure. Lesser spills identified in informal discussions with the oil industry include a tank spillage of crude oil from a well test tank in the amount of 2,000 barrels and a fuel oil spill from a storage tank also in the amount of 2,000 barrels.

Alaskan Petroleum Reserves

Alaskan petroleum potential is still largely untested, however, it is generally judged to be considerable,and Alaskan petroleum resources are expected to be a very important part of the United States energy supply. As more data is gathered and exploratory drilling progresses,estimates of unconfirmed Alaskan petroleum reserves are periodically modified. The net result of these modifications over the past few years has been a general decrease in the level of petroleum resources expected to be found in Alaska relative to some earlier estimates, but not to any substantial extent.

In the case of proven reserves, *World Oil* [5] reports that on the basis of a May 1976 joint report published by the American Petroleum Institute and the American Gas Association, proven petroleum reserves in Alaska were established at 10.094 x 10^9 barrels at the end of 1974 and 10.037 x 10^9 barrels at the end of 1975, a decline of only 0.6%. The same report revealed that proven reserves in Alaska amount to 31% of the proven reserves of the entire United States. These proven Alaskan reserves are located on the North Slope and in Cook Inlet, with approximately 80% of the reserves associated with the North Slope field onshore Prudhoe Bay, and the remaining 20% associated with the Cook Inlet field.

Both the Gulf of Alaska and the National Petroleum Reserve in Alaska are good examples of areas which initially were judged to have very high petroleum potential but where the results of exploratory drilling conducted to date has been discouraging. As of September 1977, five dry holes have been drilled in the Gulf of Alaska while three other deep tests are in process. Reports indicate that the depth of the formations is not encouraging, and more importantly, the quality of the reservoirs located thus far have failed to meet expectations. At one time, speculation of the petroleum potential in this area ran between 15 and 20 billion barrels of recoverable oil. Similarly, estimates of petroleum potential for NPRA at one time reached 30 billion barrels. It is now judged possible, however, that the area may not have any major reserves, and there are some expressions of confidence that the area will certainly have no fields comparable to the onshore Prudhoe Bay discovery. Seven deep test wells drilled over the past two years on the most promising structures in the northeastern part of the reserve have resulted in seven dry holes.

In spite of these disappointments and possibly temporary setbacks, Alaska and its adjacent continental shelf clearly contain a major portion of the oil and gas potential of the U.S. The U.S. Geological Survey credits Alaska with 33% of the total U.S. undiscovered oil potential and 16% of the country's undiscovered gas potential. Considering only offshore areas, it is significant that over 60% of the entire outer continental shelf of the U.S. lies off the state of Alaska. In these areas, it has been estimated that Alaska holds 58% of the nation's undiscovered offshore oil potential and 41% of the nation's undiscovered offshore gas potential.

Table 4 summarizes current estimates of offshore undiscovered recoverable Alaskan oil resources [6]. Summarized in the table are the name of the potential petroleum bearing basin, the geographical location of the basin, the upper limit of the estimated range of potential resources, the statistical mean, and the ranking of these locations on the basis of the statistical mean. For ease of reference, the potential petroleum basin will be identified throughout this report by geographic location rather than basin name except in the case of the Bering Sea basins where the particular basin name must be employed. Table 4 indicates that by a substantial margin, the Chukchi Sea offers the greatest potential for offshore undiscovered recoverable Alaskan resources, followed by the Beaufort Sea with roughly half of this potential, and the Zhemchug-St. George basin in the Bering Sea with nearly half again the potential of the Beaufort Sea basin. Cook Inlet and the Gulf of Alaska are the areas offering the fourth and fifth greatest potential, respectively. Figure 3 is a map showing the location of these basins with the circled number indicating the ranking of its petroleum potential based upon the statistical mean.

There is also good potential for further onshore discoveries of oil and gas in Alaska, but further discoveries on the order of the currently producing North Slope field in the Prudhoe Bay area are not expected. Alaskan onshore sediment-free basins having petroleum potential are shown in Figure 4. Onshore potential can be grouped into three general areas, including the North Slope, the interior basins, and the land fringes of offshore basins. Also shown on Figure 4 is the route of the trans-Alaska pipeline system which is currently transporting crude oil from onshore development on the North Slope of Prudhoe Bay to the trans-shipment terminal at Valdez.

Lease-Sale Schedule

Considering this nation's need for energy, the growing balance of payments problem largely associated with the importation of the bulk of our crude oil, and the vast petroleum development potential of Alaska, the delay in exploratory activities directed towards further defining the petroleum potential of the state might be considered puzzling. In spite of the petroleum industry's success in upper Cook Inlet and on the North Slope, many interesting geological formations remain untested. The problem is simply that few areas have been made available by the government for industry to explore. Onshore petroleum development is impeded by the unique complexity of the land ownership situation in Alaska that has evolved from the previous 98% ownership by the federal government. This ownership uncertainty is clearly one of the reasons for the general lack of activity by industry in onshore areas, except in those areas where clear land ownership has been established. Ownership of over half of Alaska's land, including several areas having petroleum potential, will not be established until the mid-1980's at best, and with expected litigation, more probably well beyond that time. Two of the larger land withdrawals made by the federal government in the Alaskan Statehood Act of 1958 were the Naval Petroleum Reserve No. 4, since renamed National Petroleum Reserve in Alaska, and the Arctic Wildlife Refuge. Together, these two areas occupy about two-thirds of the petroleum rich Alaskan North Slope. In addition to federal-state land claim disputes, Alaskan natives have also claimed ownership of many areas under the Alaskan Native Claim Settlement Act of 1971, which provides that 40 million acres of land will be made available

TABLE 4. ESTIMATES OF OFFSHORE UNDISCOVERED RECOVERABLE ALASKAN OIL RESOURCES [6]

Basin	Geographical Location	Maximum of Range, billion bbl	Statistical Mean, billion bbl	Ranking
Beaufort Sea	Beaufort Sea	7.6	3.28	2
Chukchi Sea	Chukchi Sea	18.1	6.30	1
Hope Basin	Kotzebue Sound	2.6	0.13	10
Norton Basin	Norton Sound	2.2	0.54	7
St. Matthew Basin	Bering Sea	negligible	negligible	12
Navarin Basin	Bering Sea	1.9	0.36	8
Zhemchug-St. George Basin	Bering Sea	5.1	1.32	3
Bristol Basin	Bristol Bay	2.5	0.71	6
Shumagin Shelf	Aleutian Shelf	0.25	0.04	11
Kodiak Shelf	Kodiak Shelf	1.1	0.23	9
Cook Inlet	Cook Inlet	2.3	1.19	4
Gulf of Alaska	Gulf of Alaska	4.4	1.13	5

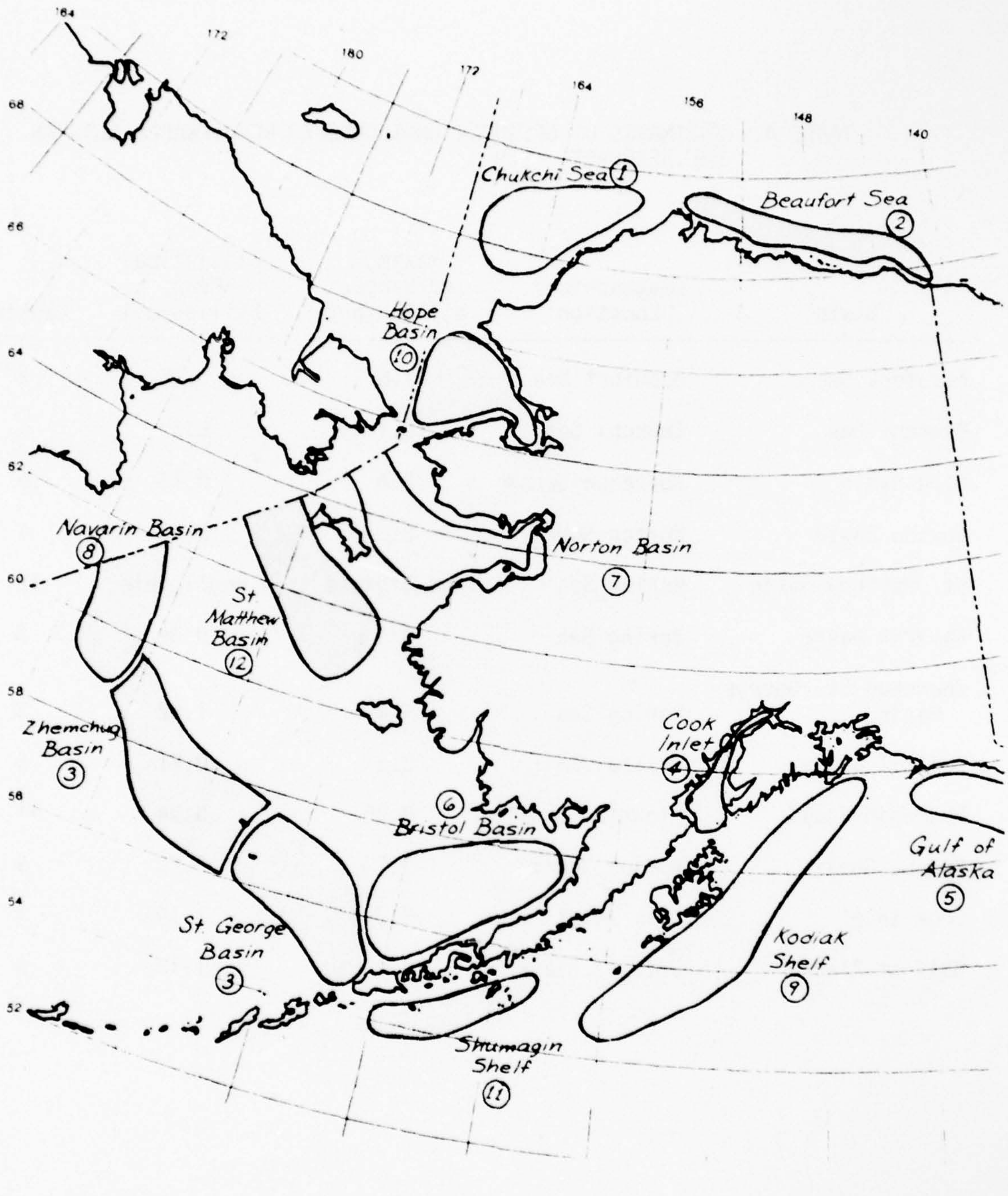


Figure 3. Alaska's Offshore Basins Showing Potential Petroleum Ranking

Figure 4. Alaska's Onshore Basins

to Alaskan native villages and regional corporations. Over 100 million acres have been withdrawn, out of which the 40 million acres will be selected. The delays in conveying lands to the native corporations by the federal government, complicated by numerous law suits, have resulted in a slower than expected pace of exploration for petroleum on native lands. It is presently projected that when all ownerships have finally been established, the federal government will retain approximately 59% of Alaska's land, the state will own approximately 30%, and the Alaskan natives approximately 11%. A negligible amount will be under private ownership resulting from homesteading and mineral claims.

For offshore areas, the Department of Interior was charged under the OCS Land Act of 1953 with administering the mineral development of the Outer Continental Shelf. In the case of oil and gas development and production, the Department's responsibilities include the selection of areas for leasing, the supervision of geological and geophysical exploration, ensuring that environmental protection requirements of the National Environmental Policy Act are met, the evaluation of resources for determining the resource sale price, the conduct of competitive bidding for resources, and the supervision of exploratory drilling and production activities on awarded leases.

The recent history of OCS lease-sales, characterized by periodic changes resulting in delays, and in some cases cancellations, of the sales, could be described as discouraging to the petroleum industry. In OCS areas, the primary problem resulting in lease-sale delays has been concern for environmental protection. In some cases, the state has negotiated with industry to buy back tracts which had already been leased but were subsequently found to be in areas of extreme ecological sensitivity. These buy-backs were largely prompted by objections from fishermen and conservationists who feared the loss of spawning grounds for marine life in the lease-sale area.

On 8 February 1977, Interior Secretary Cecil Andres announced in conjunction with the cancellation of lease-sales scheduled for 23 February 1977 covering lower Cook Inlet that he intended to review all offshore lease-sale schedules, revise them where necessary, and issue a lease-sale schedule to which the Department of Interior would be firmly committed. The first lease-sale schedule prepared by DOI under Secretary Andres was released in August of 1977. Table 5 summarizes DOI's leasing schedule for offshore Alaska. Industry interpreted this leasing schedule as imposing severe setbacks on the development of Alaska's offshore petroleum resources. In comparison to the previous leasing schedule, only the lower Cook Inlet sale, originally scheduled for February of 1977, remains on the schedule for 1977, but delayed to October. Five other sales which had been scheduled under the Ford Administration to occur in 1977 and 1978 have been removed from the schedule entirely. These sale areas included Kotzebue Sound, Norton Sound, Bristol Bay, St. George Basin, and the Aleutian Shelf. For the lower Cook Inlet sale, 120 tracts covering 683,182 acres in water depths of 150 to 500 feet have been designated. The nearshore Beaufort Sea sale will be a joint state-federal sale which will include acreage whose ownership is being disputed by the state and federal governments. The decision to postpone the Kodiak

TABLE 5. LEASING SCHEDULE FOR ALASKAN OFFSHORE AREAS RELEASED BY DOI IN AUGUST 1977

Area	Sale Date
Lower Cook Inlet	October 1977
Nearshore Beaufort Sea	December 1979
Gulf of Alaska	June 1980
Kodiak Shelf	October 1980
Lower Cook Inlet	March 1981
Norton Sound	December 1981

Shelf sale was considered to be a major disappointment to the petroleum industry. Originally scheduled to occur in February of 1977, and later changed to November 1977, the latest lease-sale schedule calls for the lease-sale to occur in October of 1980.

From the preceding discussion, it is obvious that the state and federal government have total control over the timing of petroleum development in Alaska, and the sequence in which the various basins having petroleum development potential undergo exploratory and development activity.

Industry Activity and Plans

The oil field which most geologists agree will be the largest Alaskan field, that of the onshore Prudhoe Bay area, is now in production supplying oil through the trans-Alaska pipeline to the port of Valdez where the oil is transferred into tankers for delivery to the lower 48 states. For Phase 1 of this operation, the trans-Alaska pipeline is to deliver 1.2 million barrels per day, while the ultimate capacity of the pipeline is set at 2 million barrels per day. Atlantic Richfield Company (ARCO), operator for the eastern half of the Prudhoe Bay field, will be producing from 55 wells averaging 11,000 barrels per day each to provide ARCO's 600,000 barrel per day input for the first phase of operation. BP Alaska, operator for the western half of the Prudhoe Bay field, will be producing from 48 wells with actual flows ranging from 5,000 barrels per day to 20,000 barrels per day, resulting in the average of 12,500 barrels per day. The industry is actively seeking out new oil that will expand the Prudhoe Bay field or result in the discovery of new reservoirs that will provide the additional oil required to fill the 2 million barrel per day pipeline to capacity.

The Department of the Interior is conducting a continuation of the Navy's exploratory drilling program in the National Petroleum Reserve in Alaska (NPRA). The seven deep wells drilled over the past two years by the Navy on the most promising structures on the northeastern part of the reserve resulted in seven dry holes. Of the seven, however, one well, that located on Cape Halkett, showed some promise revealed by sandstone and limestone saturated with residual oil. The U.S. Geological Survey, which will manage the Department of Interior's exploratory work in NPRA, has a six well program planned for the winter of 1977-1978 which will begin testing the western half of the reserve, and further investigate the Cape Halkett area. Geologists have speculated that the results of the Cape Halkett well tend to make the area offshore of NPRA increasingly attractive, however, since the shoreline is the limit of federal jurisdiction and the start of state jurisdiction, Interior's drilling program cannot extend beyond the shoreline. Indications are that the results of the Cape Halkett drilling will increase interest in the December 1979 nearshore Beaufort Sea lease-sale.

Oil seeps along the western shore of Cook Inlet were one of the first indications of the presence of petroleum resources in Alaska. The area was a site of one of the earliest petroleum exploration efforts with several shallow wells drilled between 1900 and 1906, but production was not developed due to the poor quality of the reservoirs. In 1957, producible oil was discovered at the Swanson River field. Since then, seven oil fields have been produced in upper Cook Inlet.

The oil industry demonstrated its great optimism in the petroleum potential of the Gulf of Alaska by investing $560 million in offshore tracts in April 1976. Several holes have been drilled by five semisubmersible rigs but nothing of significance has been found to date. Drilling activities are underway by Atlantic Richfield, Shell, Texaco, Exxon, and Gulf. Two other major bidders at this lease-sale, Mobil and Amoco, have yet to start drilling operations in the Gulf of Alaska.

The *Oil and Gas Journal* reported in its August 22, 1977 edition that 31 oil companies had responded to a Department of Interior questionnaire indicating their preference for lease-sales of 18 candidate offshore U.S. areas. The concensus of the replies as determined by Interior is summarized in Table 6. Three of the top five areas nationwide are seen to be in Alaska, with the Beaufort Sea top rated in Alaska, Bristol Bay ranked second, and the Bering Sea Shelf including St. George Basin, Navarin Basin, Norton Basin, and Hope Basin ranked third. Comparing industry's preferences as listed in Table 6 with the Department of Interior lease-sale schedule in Table 5 reveals that there are substantial differences between industry's preferences and Interior's plans for leasing. These differences are summarized in Table 7 which shows that three of industry's top five preferences in offshore Alaska are yet to be scheduled for lease-sales by DOI. The first lease-sale scheduled, that for lower Cook Inlet, is seen to be ranked sixth by industry in Alaska, and ranked fourteenth nationally. The high ranking by industry of the Beaufort Sea Basin, and the relatively near-term lease-sale scheduled for that basin (December 1979), reveals a similarity in judgement for this basin by industry and government. The other major discrepancy between industry preferences and government plans is in the case of Norton Sound where lease-sales have been scheduled for December 1981, but the area was not included on the DOI list for ranking by industry.

In addition to industry's preferences and governmental controls, another factor often cited as playing a major role in the development of Alaska oil and gas resources is technological constraints. It was recognized for many years within the oil industry that the Alaskan offshore region included several attractive areas for petroleum development, but the relatively high logistic costs associated with operating in Alaska, and the lack of technical expertise in offshore arctic operations, tended to discourage and delay active exploration efforts. Since the discovery of the Prudhoe Bay field in 1968, however, a considerable amount of research effort has been directed towards the development of technology for arctic petroleum operations, both in the United States and in Canada. Industry has stated several times over the past few years its position of accepting the responsibility for having the technical capability required for successful operations in the offshore arctic when it is necessary and economical to have it. This statement of policy was most recently reiterated in a report released by both government and industry entitled "Report on the National Planning Conference on the Commercial Development of the Oceans" [7]. At this national planning conference held in 1976, the Oil and Gas Panel concluded that "The oil and gas industry has provided, and will continue to provide, the technology required to safely and effectively explore for, and produce, hydrocarbons from the ocean. The massive infusion of government research and development funds is not required to

TABLE 6. INDUSTRY RANKING OF EIGHTEEN U. S. OFFSHORE AREAS AS DETERMINED BY THE U. S. DEPARTMENT OF INTERIOR

Overall Ranking	Offshore Area	Alaskan Ranking
1	Central Gulf of Mexico	-
2	Beaufort Sea	1
3	Bristol Bay	2
4	Santa Barbara Channel	-
5	Bering Sea Shelf Including St. George, Navarin, Norton, and Hope Basins	3
6	Mid-Atlantic, Cape Cod to Cape Hatteras	-
7-8 (tie)	East and West Gulf of Mexico	-
9-10 (tie)	North Atlantic and Southern California Borderland	-
11	North and Central California	-
12	Chukchi Sea	4
13	Gulf of Alaska	5
14	Cook Inlet	6
15	Kodiak Shelf	7
16	South Atlantic, Cape Hatteras to Key West	-
17	Southern Aleutian Shelf	8
18	Washington - Oregon	-

TABLE 7. COMPARISON OF INDUSTRY PREFERENCES AND DOI LEASE SALE PLANS FOR THE ALASKAN OCS

Offshore Area	Industry Ranking	Lease Sale Ranking
Beaufort Sea	1	2
Bristol Bay	2	Not Scheduled
Bering Sea Shelf	3	Not Scheduled
Chukchi Sea	4	Not Scheduled
Gulf of Alaska	5	3
Cook Inlet	6	1,5
Kodiak Shelf	7	4
Aleutian Shelf	8	Not Scheduled
Norton Sound	Not Ranked	6

ensure the availability of necessary technology." The major problem then becomes one of economic justification rather than technical capability. If discoveries are large enough, the economic incentive for the industry to rapidly develop the technology necessary to allow development operations exists. A very recent example of this is given by the research and development program associated with the discovery of massive gas fields off Melville Island in the Canadian Arctic. An accelerated research and development program will make the transportation system necessary to transport this gas from the Canadian Arctic Islands to market available within a relatively short time period. Another example of the rapid commercial development of technology for meeting unique operation conditions is the trans-Alaska pipeline which is presently being recorded as one of history's most spectacular engineering accomplishments. The enormous petroleum potential of the onshore Prudhoe Bay field was sufficient to justify the substantial investment in technology which was required to deliver the oil to market in a timely manner. Therefore, on the basis of past performance, and the stated policy of the petroleum industry, it is assumed for the purposes of this analysis that there will be no technical constraints imposed upon the development of offshore Alaskan petroleum resources between the present time and the early 1990's; that is, it is assumed that industry will continue to deliver the technology required in a timely manner.

Figure 5 is a projection of offshore Alaskan petroleum development for all regions presently identified as having petroleum potential. Identified in this chart are representative estimates of the years in which initial lease-sales, exploratory drilling and production operations will occur. It is stressed that the projection summarized in this figure is one of many possible petroleum development scenarios for offshore Alaska. This projection is presented as a representative projection of the manner in which development could occur, rather than a prediction of this petroleum development. The chart was prepared on the basis of the preceding information given in this report. The projections developed could be changed drastically by a great number of factors, including unexpected major discoveries, an unexpected lack of discoveries, a major catastrophic oil pollution incident in Alaska, variations in petroleum demand, variations in international relationships associated with the importation of petroleum products, the economics of petroleum development as effected by the cost of development operations, and allowable pricing schedules for petroleum products.

The information summarized in Figure 5 was developed on the basis that the near-term development of offshore Alaskan petroleum resources would be controlled by the most recently released lease schedule. For those areas not included in the most recent lease schedule, the sequencing of development was based upon industry's expressed interest in the various areas as summarized in Table 7, and the estimated level of recoverable petroleum resources for the various locations as summarized in Table 4. In all cases, exploratory drilling was assumed to commence in the year following these lease-sales, and the length of the exploratory drilling phase was based on including one to two years of production drilling. The length of this combined exploratory drilling and production drilling phase, characterized by the letter E in Figure 5, was adjusted based upon the estimated difficulty of conducting

Area	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Lower Cook Inlet	E				P													
Beaufort Sea		L	E				P											
Gulf of Alaska			L	E						P								
Kodiak Shelf			L	E						P								
Norton Sound				L	E						P							
Chukchi Sea					L	E						P						
Zhemchug Basin						L	E						P					
St. George Basin						L	E						P					
Bristol Bay							L	E					P					
Navarin Basin								L	E						P			
Kotzebue Sound									L	E							P	
Aleutian Shelf										L	E				P			
St. Matthew Basin													L	E				

Figure 5. Projection of Offshore Alaskan Petroleum Development for Initial Leasing (L), Exploratory Drilling (E) and Production (P).

drilling operations in the area due to the size of the potential reservoir, the environmental conditions, and the logistics difficulty. The beginning of initial production, denoted by the letter P in Figure 5, is intended to identify that time at which full production operations get underway and means are available for transporting the oil to market.

Based upon the October 1977 initial lease-sale date for lower Cook Inlet, exploration is expected to get underway in 1978 and extend through a four-year period resulting in initial production of this field in 1982. The next four geographic areas identified in Figure 5, including the Beaufort Sea, the Gulf of Alaska, the Kodiak Shelf, and Norton Sound, are similarly sequenced based on the established lease-sale dates already published by the Department of Interior. The Chukchi Sea was selected as the next area for development based upon the very high level of estimated reserves for this basin, and the fact that the technology required for drilling in the offshore Chukchi Sea will be very similar to the technology required for drilling offshore in the Beaufort Sea since initial drilling operations in both regions will be in the nearshore area between the coast and the Barrier Islands. The Zhemchug and St. George Basins are then selected for development in a parallel fashion based primarily upon the number 3 ranking given to these reservoirs by industry, and the number 3 ranking in potential petroleum reserves behind the Chukchi Sea and the Beaufort Sea. Bristol Bay is next selected for development based upon the industry's ranking of this area as second only to the Beaufort Sea, and the number 6 ranking of this area in potential reserves. The Navarin Basin is then selected for development ahead of Kotzebue Sound because of its proximity to the Zhemchug and St. George Basins, and the nearly equal level of resource potential. Kotzebue Sound is next selected for development ahead of the Aleutian Shelf primarily on the basis of the relatively high level of ecological sensitivity along the Aleutian Shelf, which will be discussed in detail in a later section of the report. The St. Matthew Basin is projected for development last because of the low confidence of there being any significant level of petroleum reserves in that basin as indicated in Table 4. The resulting projection of offshore Alaskan petroleum development therefore calls for initial lease-sales to have occurred in all basins presently identified as having petroleum potential by 1990, with initial production underway in most of the areas by 1990, and in all but the St. Matthew Basin by 1995. As related to the present study, therefore, the major conclusions to be drawn are that it is reasonable to expect exploratory drilling operations to be underway in all of the Alaskan offshore petroleum basins by the early 1990's, and that production operations are likely to be underway in all basins except for the Navarin Basin, Kotzebue Sound, the Aleutian Shelf, and St. Matthew Basin by 1990.

The marine transportation routes anticipated to be used during the exploration and production phases of petroleum development in offshore Alaska are shown in Figure 6. During the exploration phase of petroleum operations, marine transportation activities will consist of supply vessels transiting between supply points or staging areas and the various drilling rigs. For the most part, these supply vessels will be transiting in relatively ice-free waters during the exploratory drilling phase, and therefore operating only in open water conditions. During the production phase, year-round transport of crude oil will be required and will likely be accomplished through the combination of marine transportation systems and pipelines. Marine

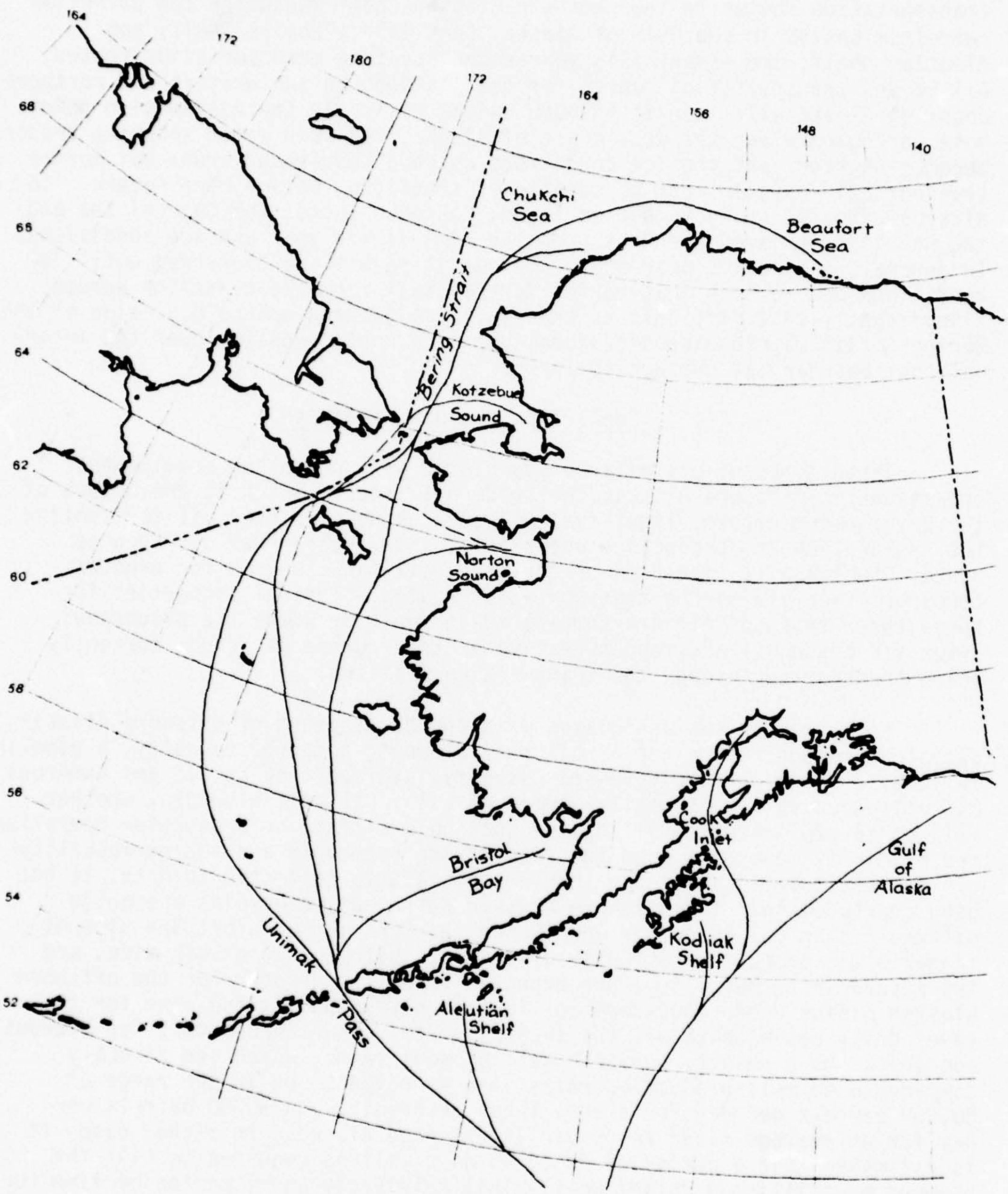


Figure 6. Marine Transportation Routes for Exploration and Production Phases of Petroleum Development for Offshore Alaska

transportation routes to the southern Alaskan Coast, including the potential petroleum basins in the Gulf of Alaska, Cook Inlet, Kodiak Shelf, and Aleutian Shelf, are essentially year-round ice-free transportation routes. All marine transportation routes for destinations on the western and northern coast of Alaska will transit through Unimak Pass. As the destination points move northward along the west coast of Alaska, the open water shipping season becomes shorter, and the ice conditions which a year-round crude oil marine transportation system must be capable of transiting become more severe. The alternate routes shown to Norton Sound, Kotzebue Sound, the Chukchi Sea and the Beaufort Sea are dependent upon the time of the year and ice conditions. In general, the routes nearest to the coastline will be preferred until ice conditions become such that routes farther away from the coastline become significantly less difficult to transit. Ice jamming on the U.S. side of the Bering Strait may require occasional use of a route crossing over the international boundary at the Bering Strait.

Spill Type, Volume, and Rate

Three types of oil will be associated with petroleum development operations in offshore Alaska; the crude oil itself which is the object of the development effort, light fuel oil such as No. 2 diesel oil for fueling the exploration and production operations, and a heavy fuel oil such as bunker C which will likely power the crude oil tankers used for product transportation via marine transportation routes. Typical properties for these three types of oil are summarized in Table 8, where the properties given for crude oil are representative of the Prudhoe Bay crude currently being transported through the trans-Alaska pipeline.

Spill mechanisms associated with the development of offshore Alaskan petroleum resources include an oil well blowout, a tanker casualty, a pipeline failure, a barge or supply vessel casualty, storage tank spills and numerous miscellaneous spills of small volumes of oil. Oil well blowouts, whether related to exploratory drilling, production drilling, or production operations, are primarily dependent upon the size of the reservoir and the permeability of the reservoir. Based upon the geological data collected to date, it has been concluded that the offshore Alaskan petroleum reservoirs are quite different than the reservoir upon which the Canadian Beaufort Sea blowout scenario was based as previously discussed. Both the reservoir size, and the reservoir permeability, are expected to be far greater for the offshore Alaskan basins under consideration in this study than is the case for the river delta basin which was the subject of the Canadian Beaufort Sea blowout scenario. As a result, possible well blowout rates, which are directly comparable to well production rates, are expected to be in the range of 50,000 barrels per day for a very large reservoir, and 5,000 barrels per day for an average sized reservoir in offshore Alaska. In either case, it is estimated that a period of 30 to 45 days will be required to kill the blowout by drilling a relief well. This relatively short period of time for drilling the relief well is based upon the assumption that a completed relief well pad will exist prior to the start of exploratory drilling, being constructed at the same time the primary pad is constructed. The relief well drilling program, therefore, starts with the transit and placement of the relief well drilling rig on the previously prepared pad, rather than starting

TABLE 8. SELECTED PROPERTIES FOR THE PRIMARY OILS ASSOCIATED WITH OFFSHORE ALASKAN PETROLEUM DEVELOPMENT

Type of Oil	Specific Gravity °API	Viscosity at 100°F SSU	Pour Point, °F
Crude	27	83	- 5
Arctic Diesel	42	28	-70
Bunker C	10 to 18	Variable	Variable

with the preparation of the relief well drilling pad itself. Two oil well blowout situations have, therefore, been defined as a 50,000 barrel per day release from a very large field for a 30 to 45 day period resulting in a maximum release of 2,250,000 barrels of crude oil, and a smaller well blowout of 5,000 barrels per day from an average size field for a period of 30 to 45 days resulting in a maximum release of 225,000 barrels of crude oil.

A second spill mode associated with the development of offshore Alaskan resources is that of a pipeline spill. The pipeline spill could be associated with the production of an individual well through a gathering pipeline, or it could be associated with a larger pipeline which is handling the production of numerous wells downstream of the gathering lines. For offshore operations, these gathering lines will be sub-sea pipelines. While it is likely that a catastrophic failure of one of these pipelines would result in a relatively small release of oil due to the capability to shut down production within minutes through the use of check valves in the line, the existing precedent for pipeline spills in Alaska has been established by the Alyeska Pipeline System which designed the trans-Alaska pipeline such that the largest volume spilled due to a catastrophic line failure would be 50,000 barrels. However, since individual gathering lines to offshore structures would be much smaller in diameter and far shorter in length, and since the production line downstream of several gathering lines would also be relatively short, the maximum spill associated with the pipeline rupture is taken as 15,000 barrels.

Tanker casualties resulting in the release of crude oil can occur due to groundings, collisions, fires, explosions, structural failures, and mechanical breakdowns. Historically, vessel casualties account for about 18% of the oil spilled worldwide from tanker operations. While controls on marine transportation systems transiting Alaskan waters are expected to be far more rigid than those applied to worldwide shipping, the possibility of a tanker casualty must be considered. The Valdez to west coast tanker fleet being used for the transport of Prudhoe Bay crude will eventually consist of 35 tankers ranging in size from 45,000 to 150,000 dwt. The great majority of these vessles, 21 of the 35, will be in the 120,000 to 130,000 dwt range. Selecting a 120,000 dwt tanker as representative, such a vessel will have a crude oil capacity of about 850,000 barrels of oil. Older vessels are typically subdivided into 30 cargo holds, while the newer vessels are subdivided into 15 cargo holds. Based upon dividing the 850,000 barrel cargo equally among 15 cargo holds results in the capacity of an average hold of 57,000 barrels. For the purposes of this study, therefore, oil spills associated with tanker casualties are based on the rupture of a single cargo hold resulting in the release of about 50,000 barrels of crude oil.

The transportation of refined petroleum products to various staging areas and small communities located along the Alaskan coast is typically done through the use of small tank vessels or barges having capacities of 40,000 barrels, 90,000 barrels and 130,000 barrels of cargo. The smaller barges typically have 18 cargo tanks, while the larger ones generally have 30 tanks. Basing the oil spill associated with this type of operation on the assumption that 2 to 4 tanks are ruptured for the large and small barges respectively, this spill is defined as an instantaneous release of 10,000 barrels of Arctic diesel fuel.

Oil spills of residual fuels such as bunker C are associated with the marine transportation of crude oil. It has been estimated that the fuel requirements for a 120,000 dwt tanker operating on a route including some open water and some ice infested waters will require about 8,000 tons of fuel oil for a 6,000 mile round trip voyage. Based upon a tank rupture associated with about one-eighth of the vessel's fuel, it is reasonable to select a 1,000 ton spill of bunker C (7,000 barrels) as the release of residual fuel oil associated with the marine transportation of crude oil.

Numerous miscellaneous spill mechanisms can be developed based upon spillage associated with terminal operations, tanker transfer operations, tank farm ruptures, loss of small vessels, etc. In all these cases, however, the release of oil is judged to be very small in comparison to the releases associated with the preceding spill mechanisms, and for the purposes of this study, they will be considered negligible. On the basis of the preceding analysis, the spill modes selected for use in this study are summarized in Table 9.

Environmental Conditions

Recalling that the objective of this portion of the program is to determine oil spill scenarios that encompass the majority of spill and environmental conditions likely to be encountered in Alaska, this section of the report is directed towards the definition of the environmental conditions in which offshore Alaskan petroleum development operations and the associated oil spill response efforts must be conducted. This description of environmental conditions is presented in the following report subsections devoted to ice conditions, air temperatures, water depths, water currents, waves, tides, water temperatures, light, precipitation, visibility, wind and storms, and earthquakes. All of these environmental conditions are then summarized in a broad overview of significant environmental conditions for offshore Alaskan operations.

Ice Conditions

Ice conditions in Alaskan waters vary considerably as a function of location and season. In order to simplify the presentation of ice conditions in Alaskan waters and to establish a standardized procedure for future reference, ice conditions will be defined in terms of ice zones and as a function of calendar time for each geographic area. In general, three types of ice will be present in each ice zone, including level ice, broken ice, and pressure ridges. Level ice is defined as ice of a single thickness, while broken ice is defined as ice which has fractured into pieces, and a pressure ridge is defined as a wall of ice having a keel depth equal to five times the level ice thickness and a sail height equal to twice the level ice thickness. Based upon these definitions, the ice zones established for use in this study are as defined in Table 10.

Ice conditions selected as being representative for each month are shown in Figures 7 through 18. It must be recognized that in all areas, more or less severe ice conditions could occur depending upon whether that particular year was a severe or mild ice year. It must also be recognized that the

TABLE 9. SUMMARY OF REPRESENTATIVE OIL SPILL MODES SELECTED FOR THIS STUDY

Spill Mechanism	Type of Oil	Volume Released bbl	Release Rate	Release Period days
Oil Well Blowout - Very Large Field	Crude	2,250,000	50,000 bbl/day	45
Oil Well Blowout - Average Field	Crude	225,000	5,000 bbl/day	45
Tanker Casualty	Crude	50,000	Instantaneous	--
Pipeline Casualty	Crude	15,000	Instantaneous	--
Tanker Casualty	Bunker C	7,000	Instantaneous	--
Supply Vessel Casualty	Arctic Diesel	10,000	Instantaneous	--

TABLE 10. DEFINITION OF ICE ZONES FOR USE IN THIS STUDY

Ice Zone	Level Ice Thickness feet	Pressure Ridge Keel Draft feet
0	0 (open water)	0 (open water)
1	1	5
2	2	10
3	3	15
4	4	20
5	5	25
6	6	30
7	7	35
8	Shear Zone	Shear Zone

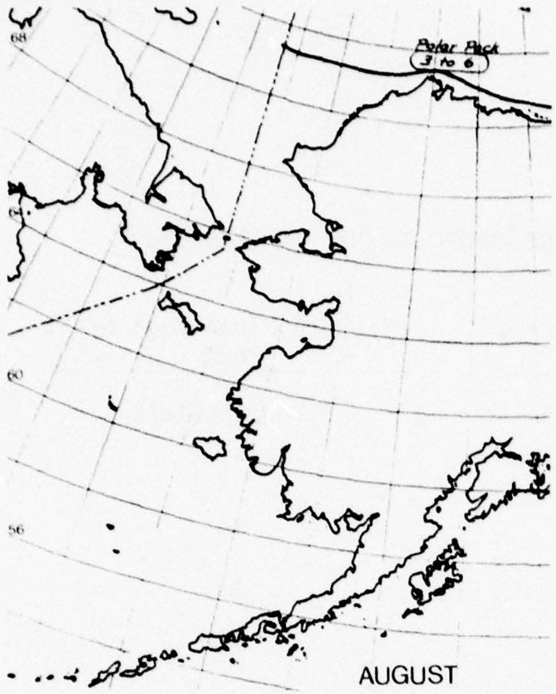


Figure 7. Typical Ice Conditions in August

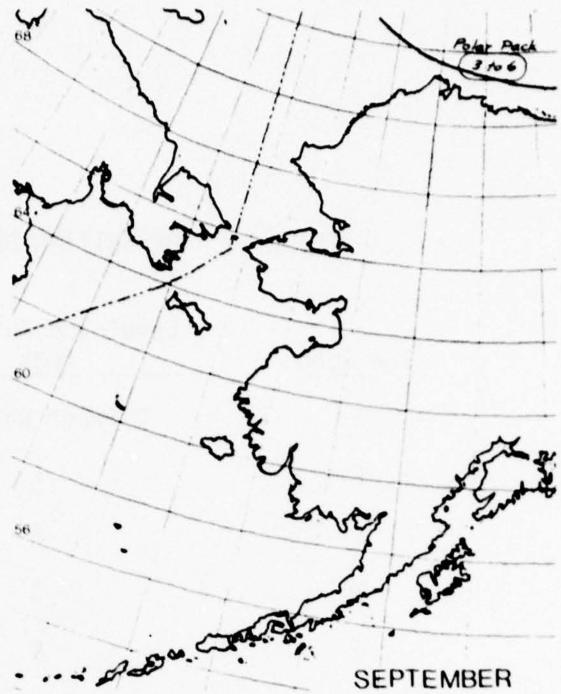


Figure 8. Typical Ice Conditions in September

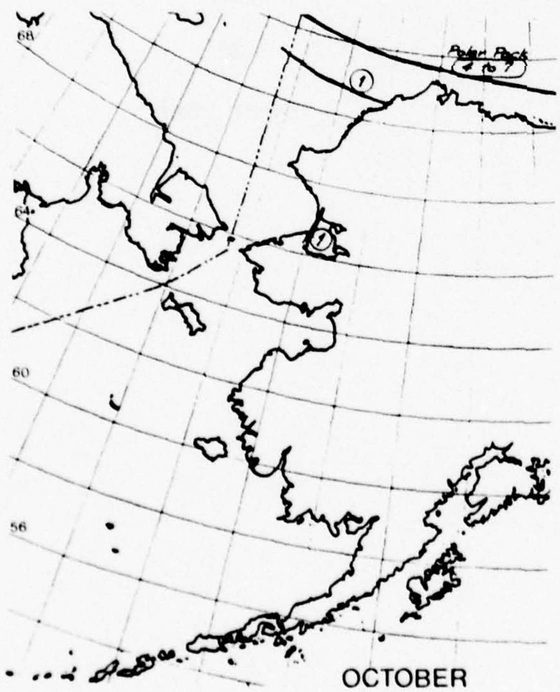


Figure 9. Typical Ice Conditions in October

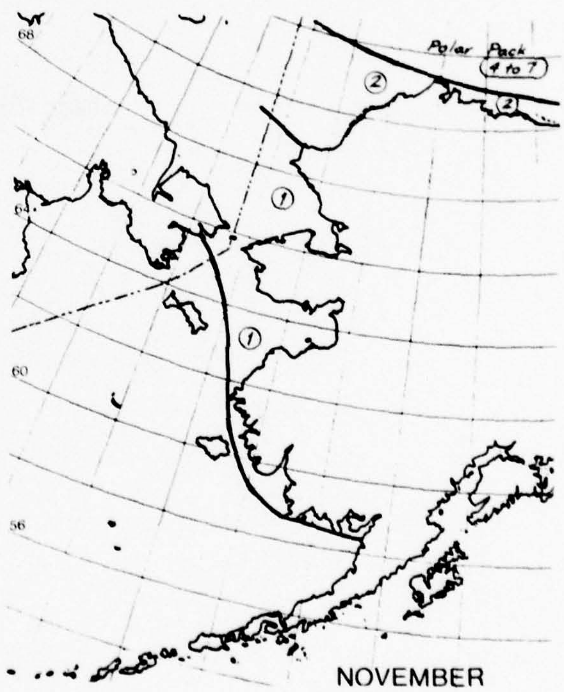


Figure 10. Typical Ice Conditions in November

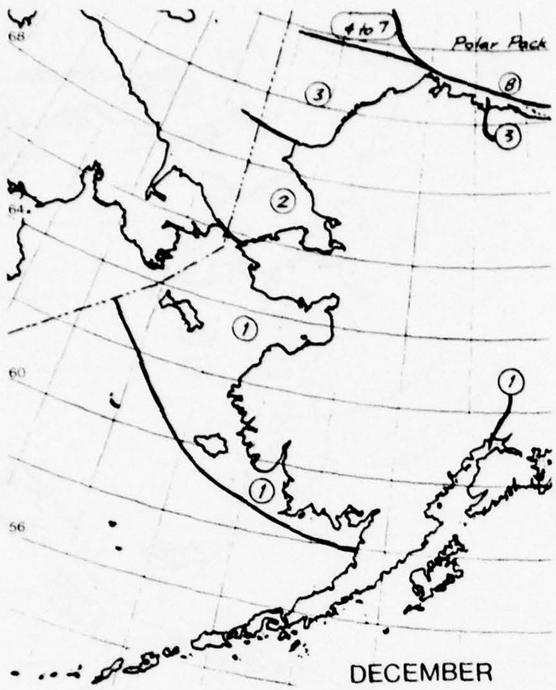


Figure 11. Typical Ice Conditions in December

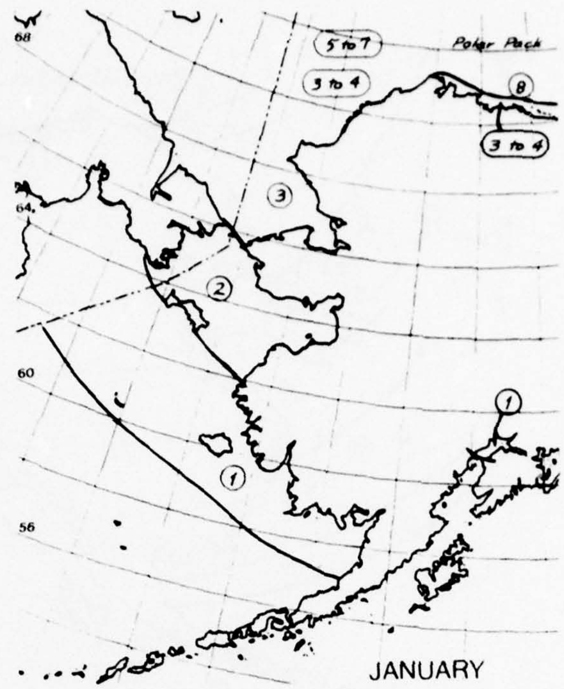


Figure 12. Typical Ice Conditions in January

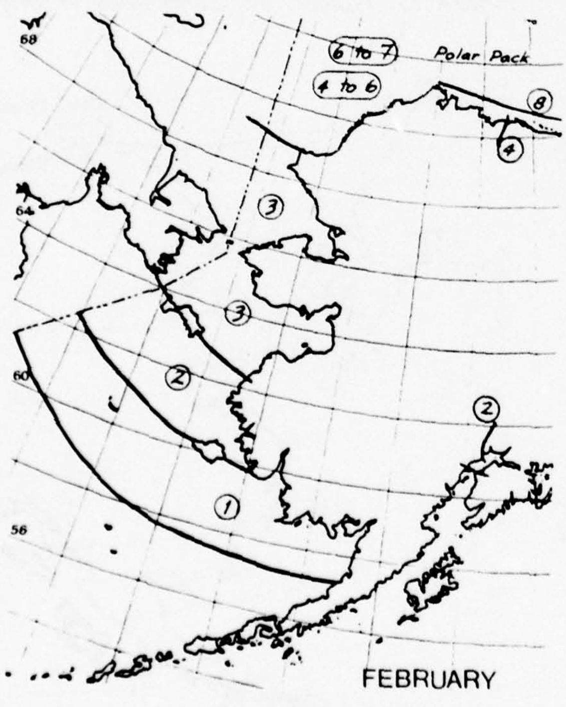


Figure 13. Typical Ice Conditions in February

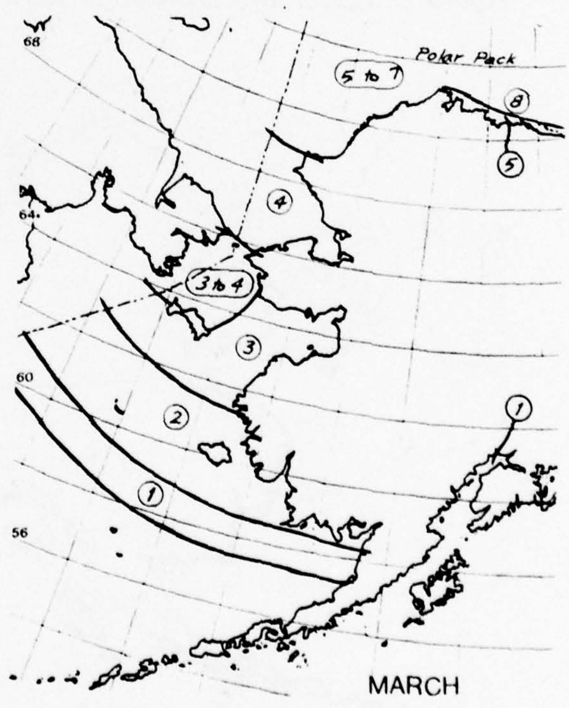


Figure 14. Typical Ice Conditions in March

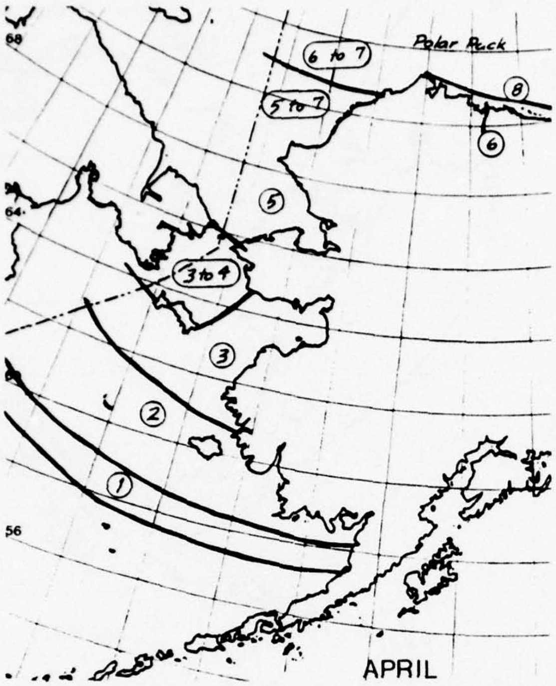


Figure 15. Typical Ice Conditions in April

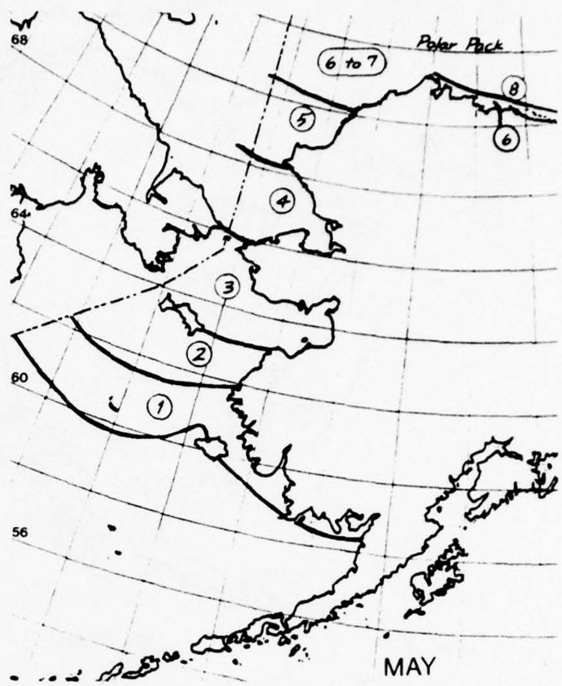


Figure 16. Typical Ice Conditions in May

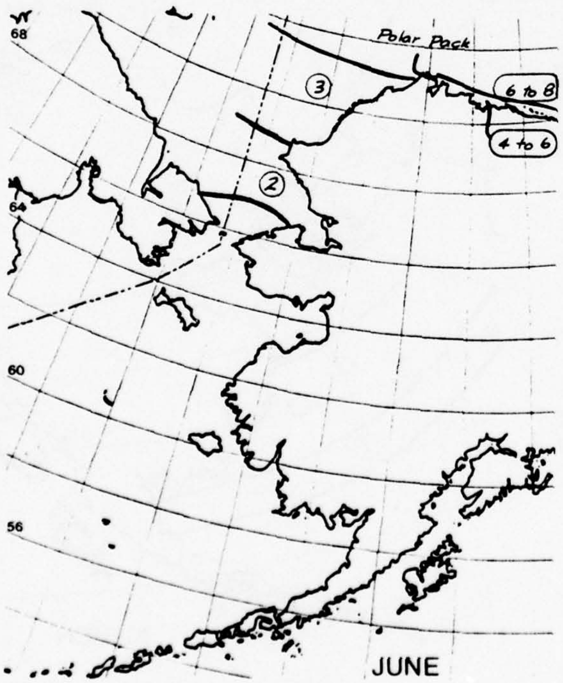


Figure 17. Typical Ice Conditions in June

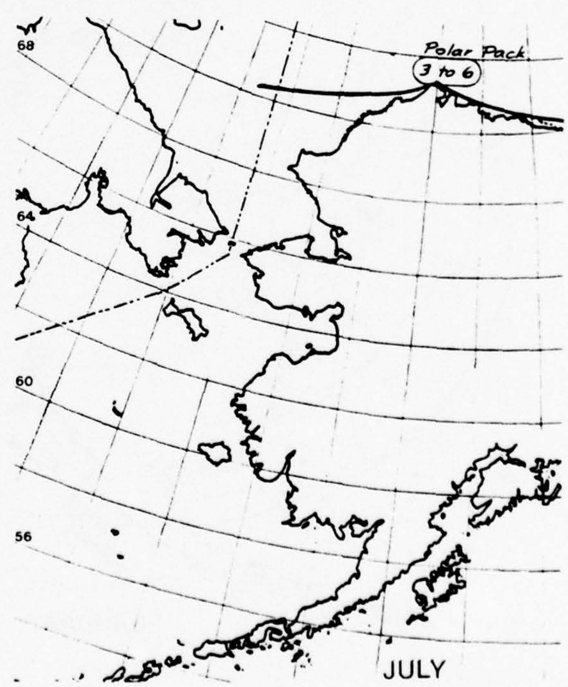


Figure 18. Typical Ice Conditions in July

distribution of pressure ridges, and the pressure ridge keel depth and sail height vary greatly within any zone. Broad generalizations have been made to characterize representative conditions for the purpose of this study. These monthly maps of ice conditions were based primarily upon data gathered and published by the Naval Oceanographic Office [8].

Reviewing these figures, it is seen that on the basis of representative ice conditions, the entire coast of Alaska is ice free in the months of August and September. In October, the freeze-up has proceeded southward such that the Beaufort Sea and the Northern Chukchi Sea are in Ice Zone 1, and Kotzebue Sound has started to freeze up. In November, the freeze-up continues to proceed southward along the western coast of Alaska with Ice Zone 1 extending from the northern extreme of Kotzebue Sound, encompassing Norton Sound, and sweeping close to the coast down into the northern extremes of Bristol Bay. During this process, the freeze-up continues in the Chukchi and Beaufort Seas with the coastal ice increasing to a Zone 2 classification. In December, ice growth continues so that the coastal Beaufort and Chukchi areas are now classified as Ice Zone 3, Kotzebue Sound as Ice Zone 2, and Ice Zone 1 expands to encompass a greater portion of the Bering Sea. In addition, upper Cook Inlet is now classified as Ice Zone 1. Ice conditions then continue to worsen along the northern and western coasts through January, February, March, and April. Over this same time period, ice conditions in upper Cook Inlet vary from Zone 1 in January, increasing to Zone 2 in February, then receding to Zone 1 in March and changing to open water in April. Ice conditions then start to diminish along the northern and western coasts in May, with the Bering Sea returning to a generally ice free condition in June. In July, the ice continues to diminish to the extent where Kotzebue Sound and the southern Chukchi Sea are now primarily open water.

In addition to these monthly ice charts of representative ice conditions, there are several special ice conditions that should be recognized. There are two major bottleneck areas that restrict the flow of ice and result in substantial ice jamming, the Bering Strait and the area between St. Lawrence Island and the Soviet coast. At both of these locations, the prevailing north to south wind drives large pieces of ice against the shoreline, creating a massive ice jam. A second special condition is the fact that in the Bering and Chukchi Seas, ice growth rates and ice decay rates along the west coast of Alaska are very rapid in their north-south and south-north movements. This movement of the ice edge is demonstrated in Figure 19 which shows the typical ice edge for each month, with the ice edge being defined as at least a 12% ice coverage. The ice edge contours demonstrate that the ice edge tends to remain relatively stationary at the northern and southern extremes of travel, and that the growth and decay of the ice is a relatively rapid process. Also shown on Figure 19 is the maximum southerly extent of the ice edge extending well south of the Pribilof Islands and just southwest of Unimak Pass. In comparing this line, indicating the maximum southerly extent of the ice edge, with the location of Alaska's offshore basins shown in Figure 3, it is concluded that all offshore exploration and production platforms intended for year-round use must be designed to withstand ice interaction forces. In the southern Bering Sea where ice thicknesses are never too great, the maximum ice forces exerted on offshore structures would result from the impact by drifting ice moving southward through the Bering Sea.

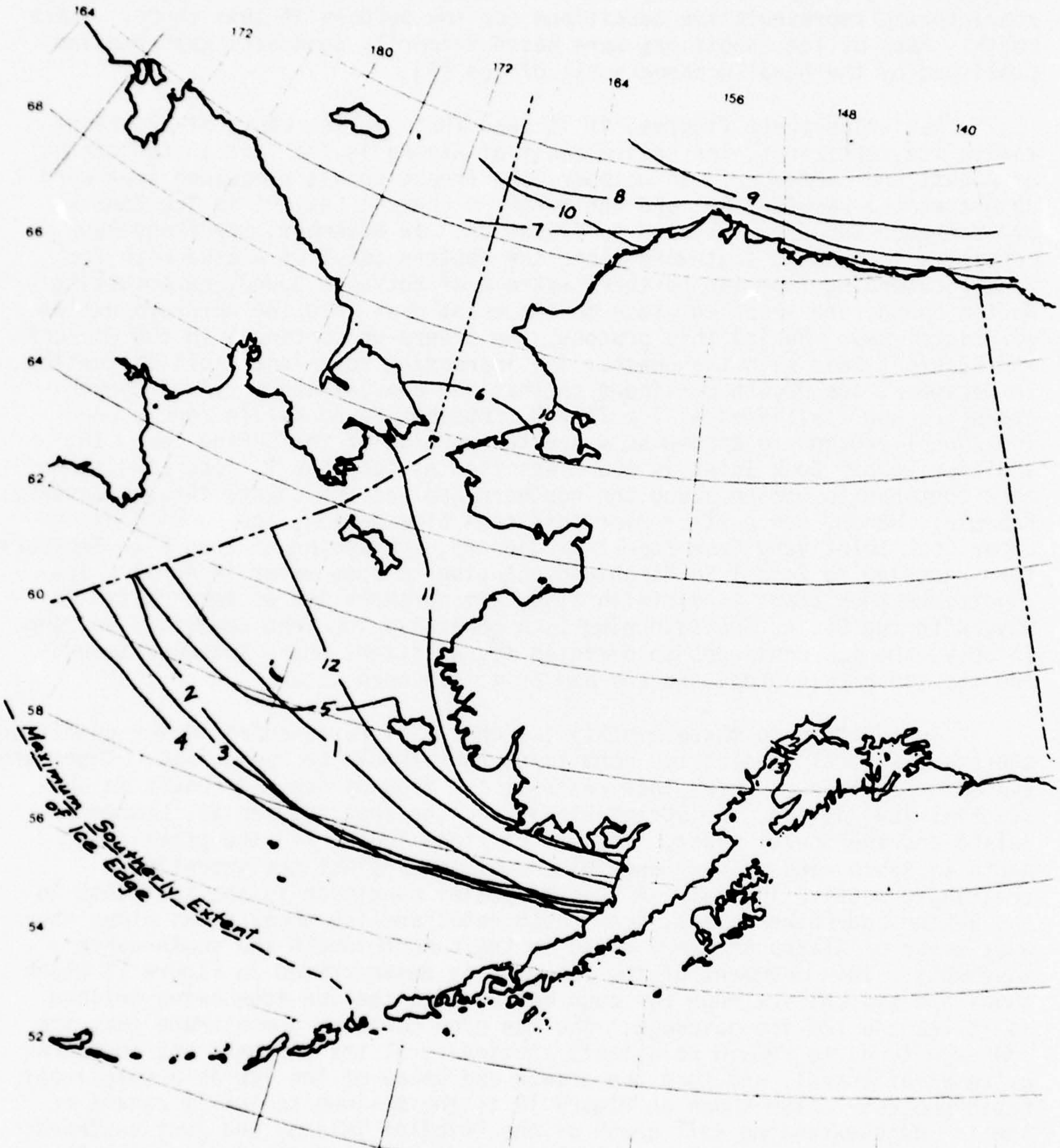


Figure 19. Monthly Ice Edge
(12% Ice Concentration)

In general, ice of relatively uniform thickness can be expected in the coastal areas, extending to as much as several miles offshore. The extent of this stable ice cover depends upon the wind forces and current forces which are acting upon the ice. Typically the ice cover on the north and west coasts of Alaska, between the coast and the Barrier Islands, remains relatively uniform and stable throughout the year with little pressure ridging and little ice movement. Beyond the Barrier Islands, ice movement and the formation of pressure ridges occur frequently at relatively nearshore locations. While for the purposes of this study a representative pressure ridge configuration has been selected, it should be pointed out that there is no such thing as a standardized pressure ridge. Pressure ridges can take many forms, including ice pileup on the surface only with no ice buildup below the surface, ice buildup entirely below the ice surface with no ice buildup on top, and all intermediate variations of above and below ice buildup. Other major variations include the extent of consolidation or refreezing of the ice rubble field, the porosity of the ridge and the ice itself, the ice piece size, and the thickness of the individual ice pieces. Therefore, while for the purposes of this study representative pressure ridge configurations were selected, it must be recognized that great variations in pressure ridge configurations and characteristics exist.

Air Temperatures

Mean monthly air temperatures at selected Alaskan coastal areas are summarized in Table 11. Point Barrow is seen to have a mean monthly air temperature ranging from a minimum of -18.9°F in February, to a maximum of 39.4°F in July, while extremes of monthly air temperatures at Anchorage range from 11.8°F in January to 57.9°F in July. In addition to extremes of mean temperatures, it is important to recognize that the severity of a freeze is a function of not only temperature but also the time over which that temperature is sustained. The preferred indication of temperature severity has been established as freezing degree days and thawing degree days, where, by definition, one degree day is equal to each degree of temperature above or below 32°F acting for each day. Figure 20 is a summary of freezing degree days for the state of Alaska [9], graphically demonstrating the temperature severity of all regions of the state. Figure 21 is a similar presentation of thawing degree days. The freezing degree days provide a basis for calculating the depth of ice and frozen ground, while the thawing degree days provide a measure of ground thaw during spring.

Water Depths

Three levels of water depth were selected as being significant for the purposes of this study. A water depth of 2 fathoms (12 feet) was selected as the most shallow contour of interest since this would define the operating limits for tugs and larger barges. The second depth contour of interest was defined as the seven fathom contour (42 feet) which was judged as the operating limit for present polar icebreakers. The final depth contour of interest was selected as the 12 fathom contour (72 feet) which would define the operating limit for crude oil supertankers. The water depth contours for the Alaskan coast are shown in Figures 22 and 23. The most outstanding feature demonstrated by these water depth contours is the relative shallowness of the entire north coast of Alaska.

TABLE 11. MEAN MONTHLY AIR TEMPERATURES AT SELECTED GEOGRAPHIC LOCATIONS (°F)

Month	Barter Island	Point Barrow	Kotzebue	Nome	Unalakleet	Pribilof Islands	King Salmon	Cold Bay	Kodiak	Anchorage
January	-15.2	-15.1	-4.5	4.4	3.4	25.5	13.4	28.2	30.4	11.8
February	-19.2	-18.9	-5.9	4.8	4.6	22.7	16.6	28.2	31.4	17.8
March	-14.7	-15.5	-1.4	7.5	9.4	24.0	20.4	29.0	32.1	23.7
April	0.1	- 0.7	12.1	19.2	22.1	28.6	31.5	33.1	36.9	35.3
May	21.1	18.9	30.8	34.3	37.8	34.7	42.6	39.5	43.2	46.2
June	34.1	33.6	43.4	45.5	48.5	41.0	50.7	45.4	49.7	54.6
July	40.0	39.4	53.1	49.8	54.0	45.6	54.5	50.1	54.1	47.9
August	38.9	38.0	50.6	49.2	51.9	47.4	53.8	51.3	54.9	55.9
September	31.6	30.4	41.3	42.0	43.5	44.7	47.3	47.3	50.0	48.1
October	16.4	16.1	23.4	28.7	27.3	38.2	33.6	39.6	40.7	34.8
November	0.2	0.0	7.7	15.9	13.3	33.3	22.1	34.3	34.8	21.1
December	-12.4	-11.0	-3.7	5.9	1.6	28.4	11.7	29.0	29.9	13.0

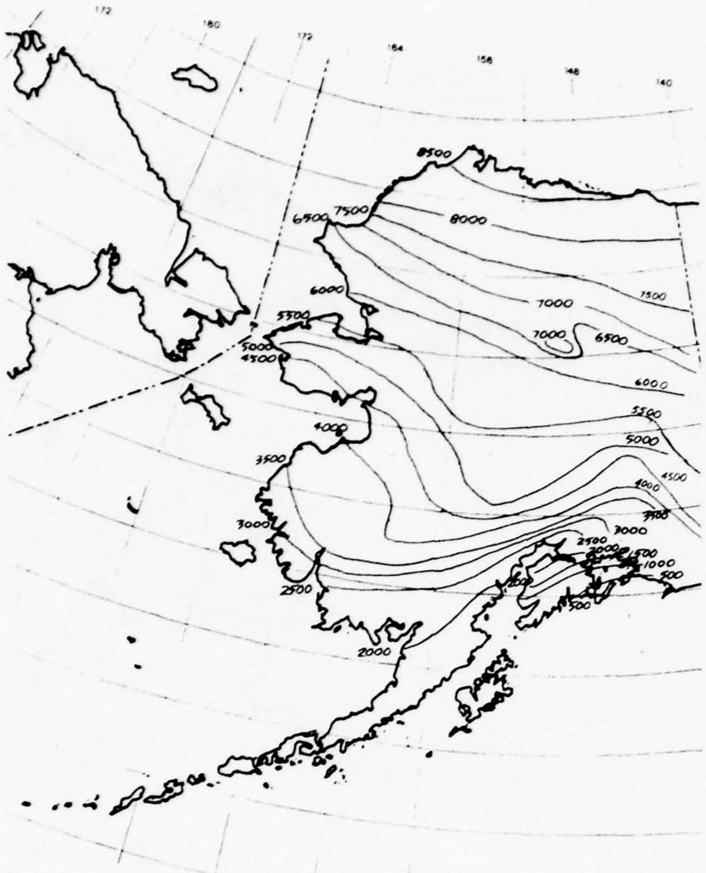


Figure 20. Freezing Degree Days

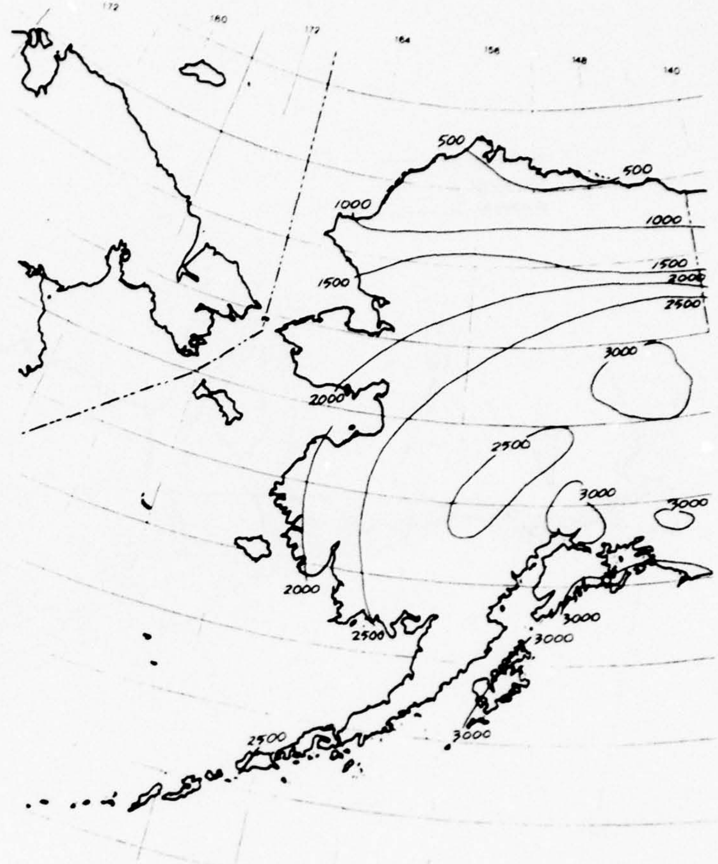


Figure 21. Thawing Degree Days

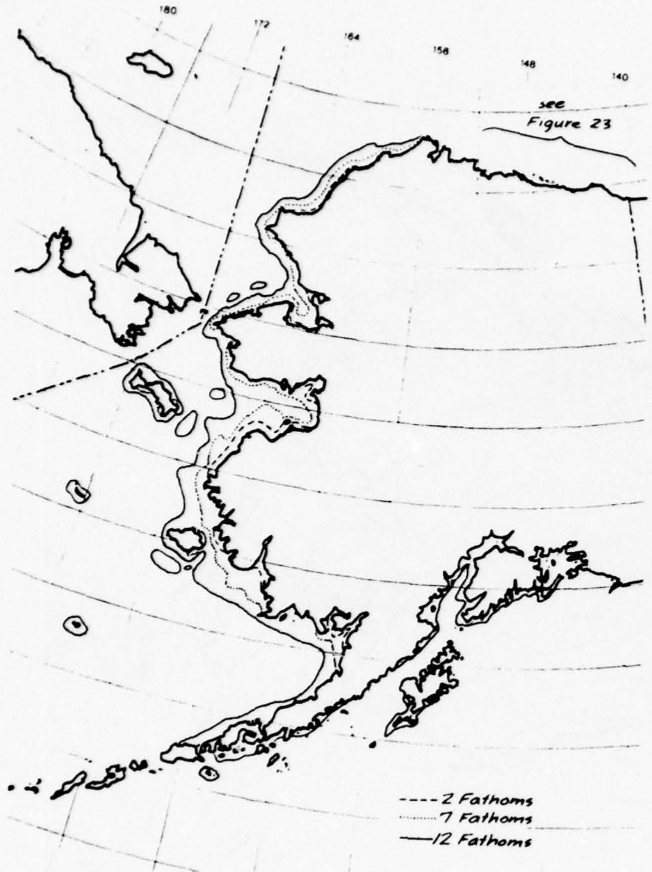


Figure 22. Water Depth Contours

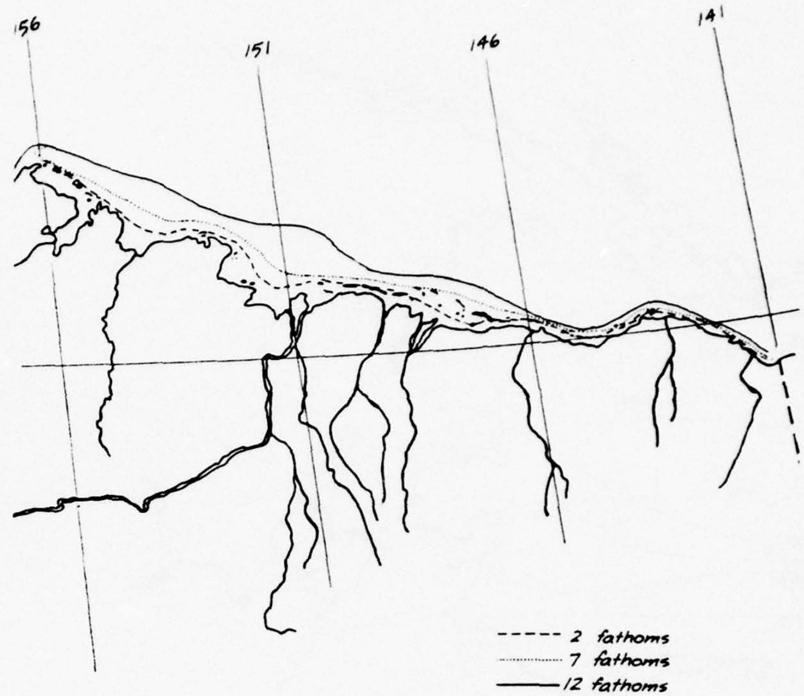


Figure 23. North Slope Water Depth Contours

Water Currents

The summer and winter surface currents for Alaskan waters are shown in Figures 24 and 25 respectively [1, 9]. Along the southern coast of Alaska, the Alaska current follows the coastline and moderates the coastal climate. Further west, limited quantities of Pacific Ocean water enter the Bering Sea through the Aleutian Island chain, producing a net flow through the Bering Strait and into the Arctic Ocean. Surface currents in Norton Sound are affected by wind action, fresh water input, convection, and influx from the Bering Sea. Surface waters flow northward past the west end of Norton Sound, while at greater depths, the influx of Bering Sea water flows inward along the bottom of the sound. River flows also modify surface water movement to some extent. In Kotzebue Sound, currents are largely tidal, although winds may cause local variations in surface currents. A net inflow occurs near Cape Espenberg, accompanied by a corresponding net outflow beyond Cape Krunsenstern. In the Beaufort Sea, surface circulation is dominated by a clockwise gyre in the Arctic Basin centered midway between Alaska and the North Pole. Westerly currents produced by this gyre set against the coast at a location east of Point Barrow and flow at the rate of 1 to 2 nautical miles per day. This prevailing current moves both water and ice shoreward throughout most of the year. Over short time periods, however, nearshore surface currents are extremely variable, generally weak, and strongly influenced by local winds. They may, therefore, set in either an easterly or westerly direction along the coast. In late summer and early fall, easterly and offshore winds produce surface currents countering and pre-vailing, at times, the Arctic gyre. This results in a period of relatively ice free water which varies in extent from year to year. In addition to the general circulation patterns shown in Figures 24 and 25, coastal currents caused by winds and tides may also be significant.

Waves

Figures 26 through 31 summarize wave conditions in Alaskan waters in terms of the percentage frequency of occurrence with which the seas can be expected to exceed 5, 8, and 12 feet in height during the summer and winter [1]. In general, seas are much more severe in winter than in summer. For the most part, rough seas are seen to be limited to the southern coast of Alaska, extending into the Bering Sea only in the summer and even then generally with wave heights less than 5 feet. It should also be noted that rough seas occur most frequently in the Gulf of Alaska during the autumn season.

Tides

Contours of tidal range for Alaskan coastal areas are shown in Figure 32. Tides in Alaska vary considerably depending upon geographic location. In the Cook Inlet and Bristol Bay areas, tidal ranges of 16 to 20 feet are common, while the tidal range along the coast of the Beaufort and Chukchi Seas is less than 1 foot.

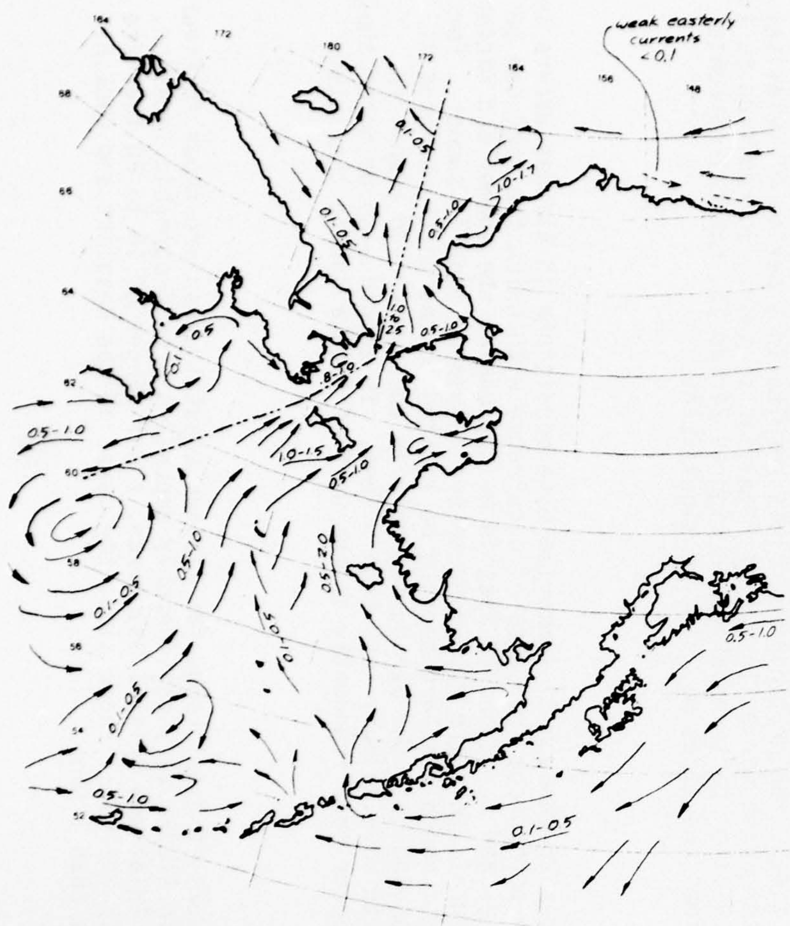


Figure 24. Surface Currents in Knots - Summer

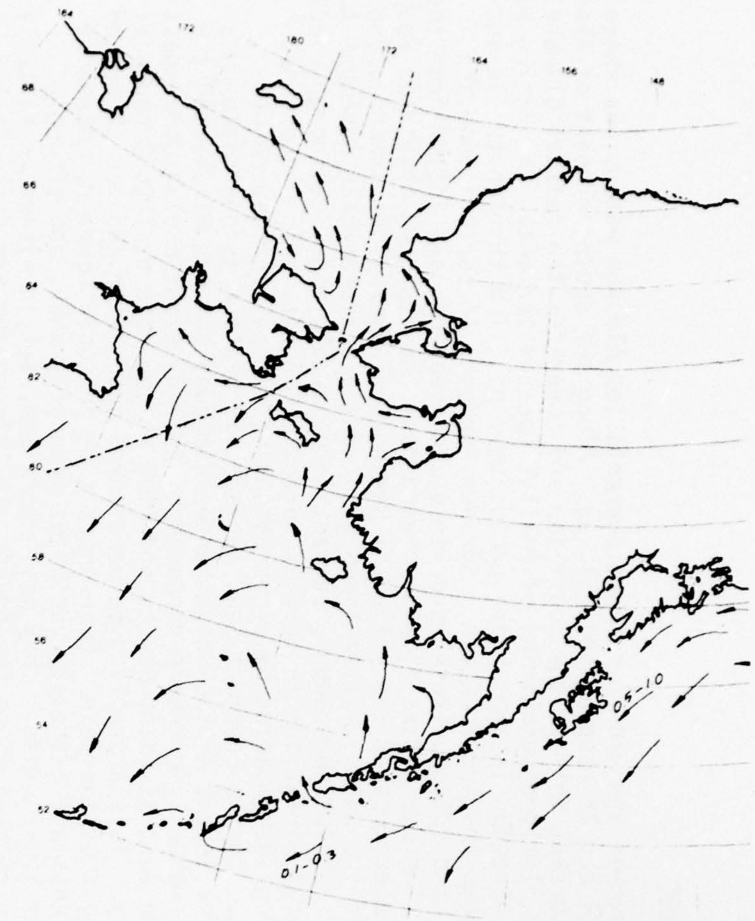


Figure 25. Surface Currents in Knots - Winter
(Note: under-ice current velocities have been poorly documented)

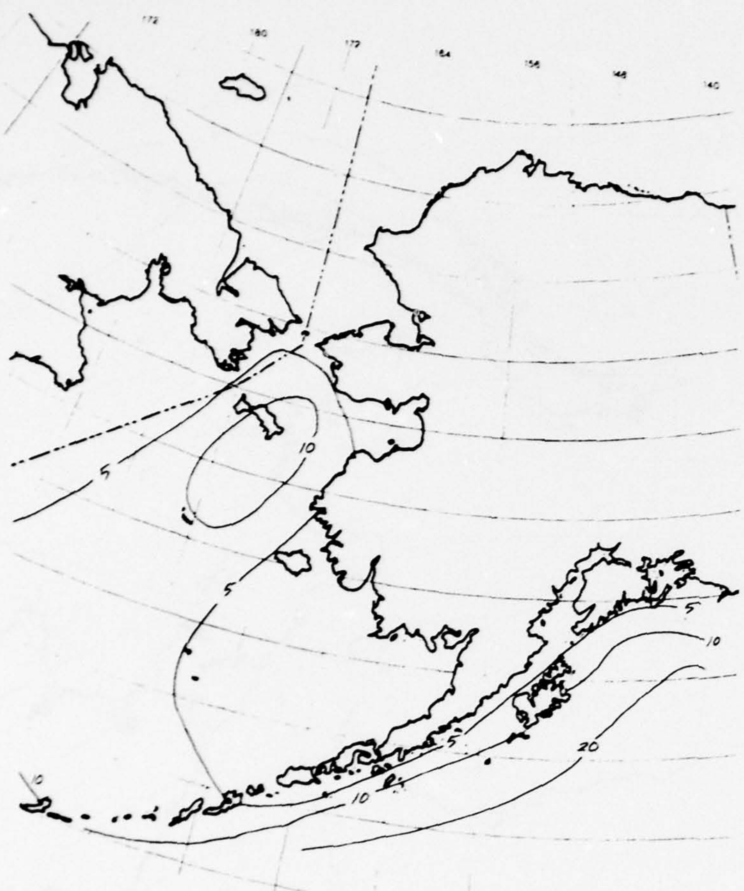


Figure 26. Wave Heights ≥ 5 ft. in Summer
Percentage Frequency of Occurence

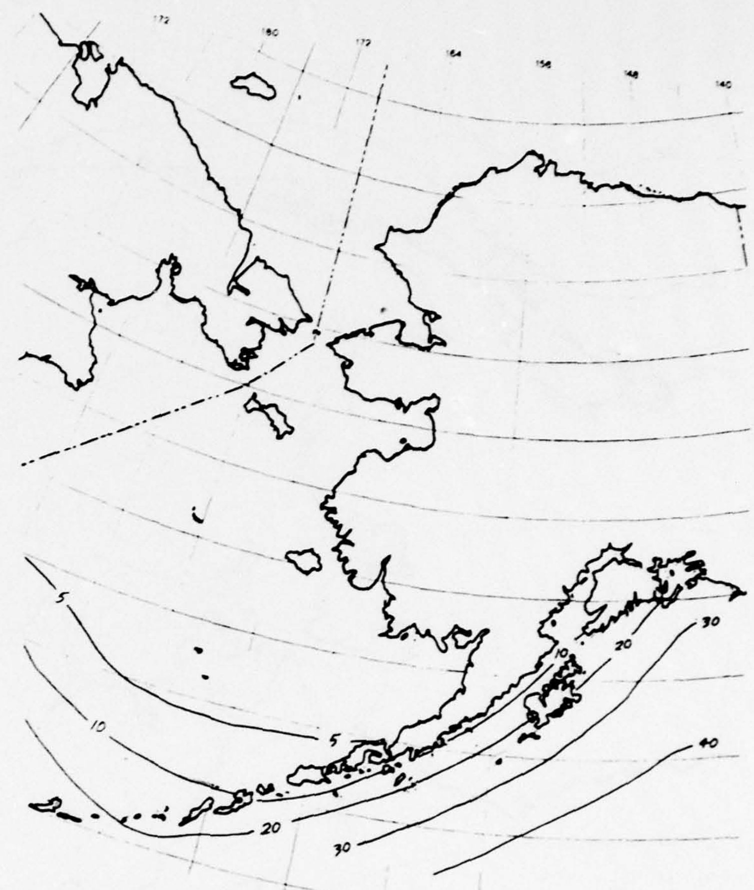


Figure 27. Wave Heights ≥ 5 ft. in Winter
Percentage Frequency of Occurence

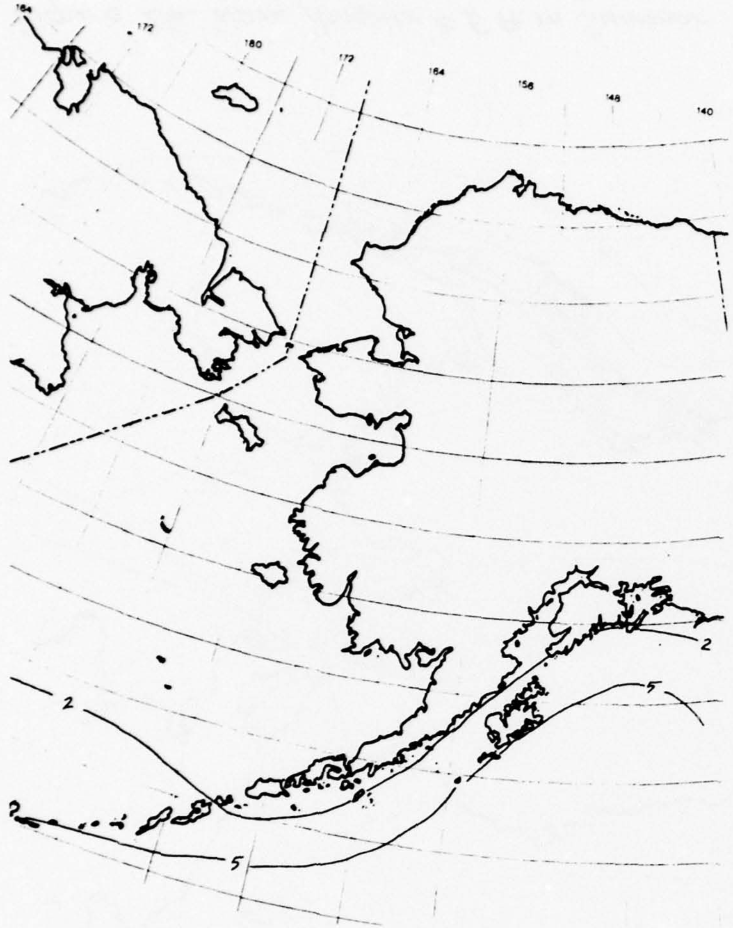


Figure 28. Wave Heights ≥8 ft. in Summer
Percentage Frequency of Occurence

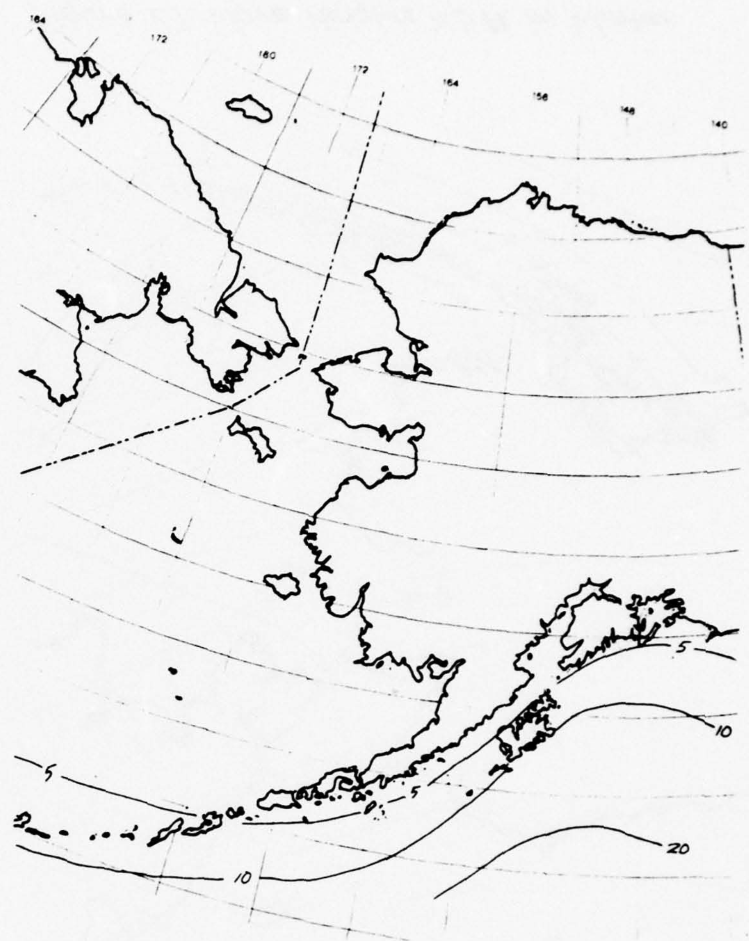


Figure 29. Wave Heights ≥8 ft. in Winter
Percentage Frequency of Occurence

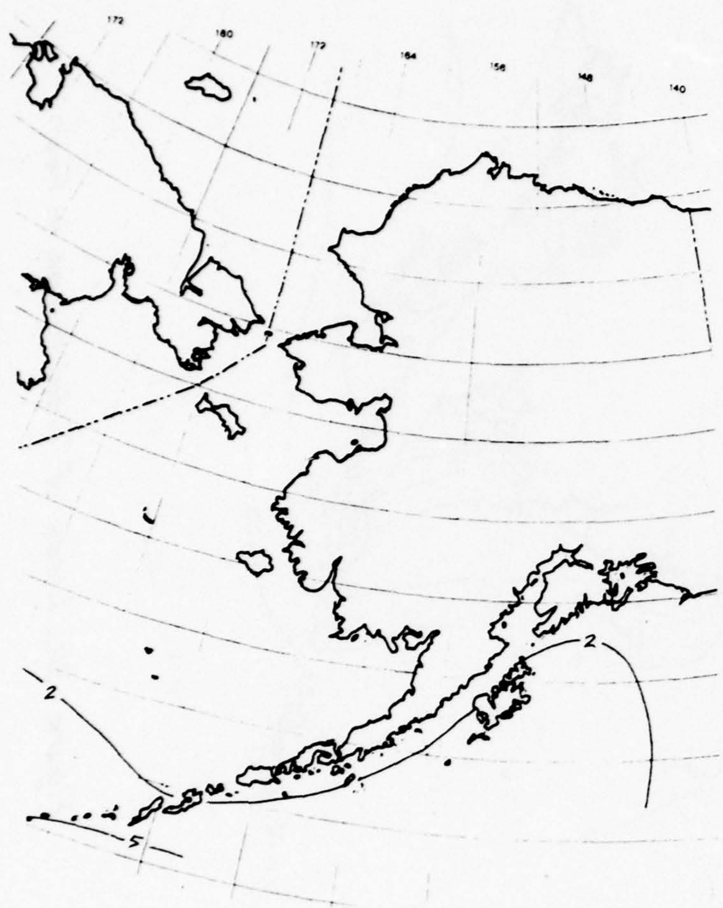


Figure 30. Wave Heights ≥ 12 ft. in Summer
Percentage Frequency of Occurence

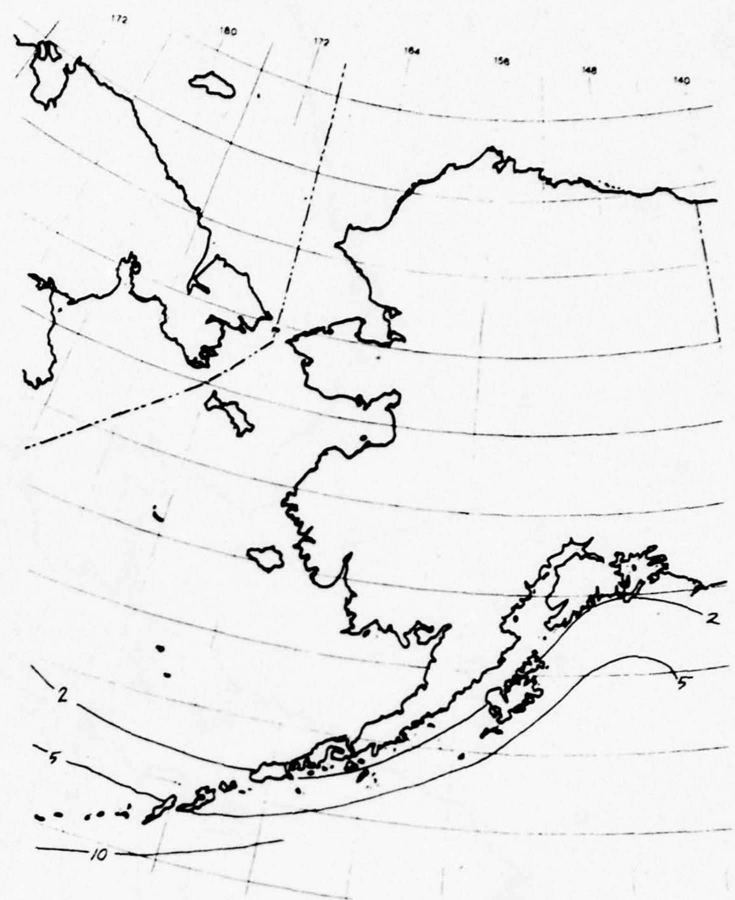


Figure 31. Wave Heights ≥ 12 ft. in Winter
Percentage Frequency of Occurence

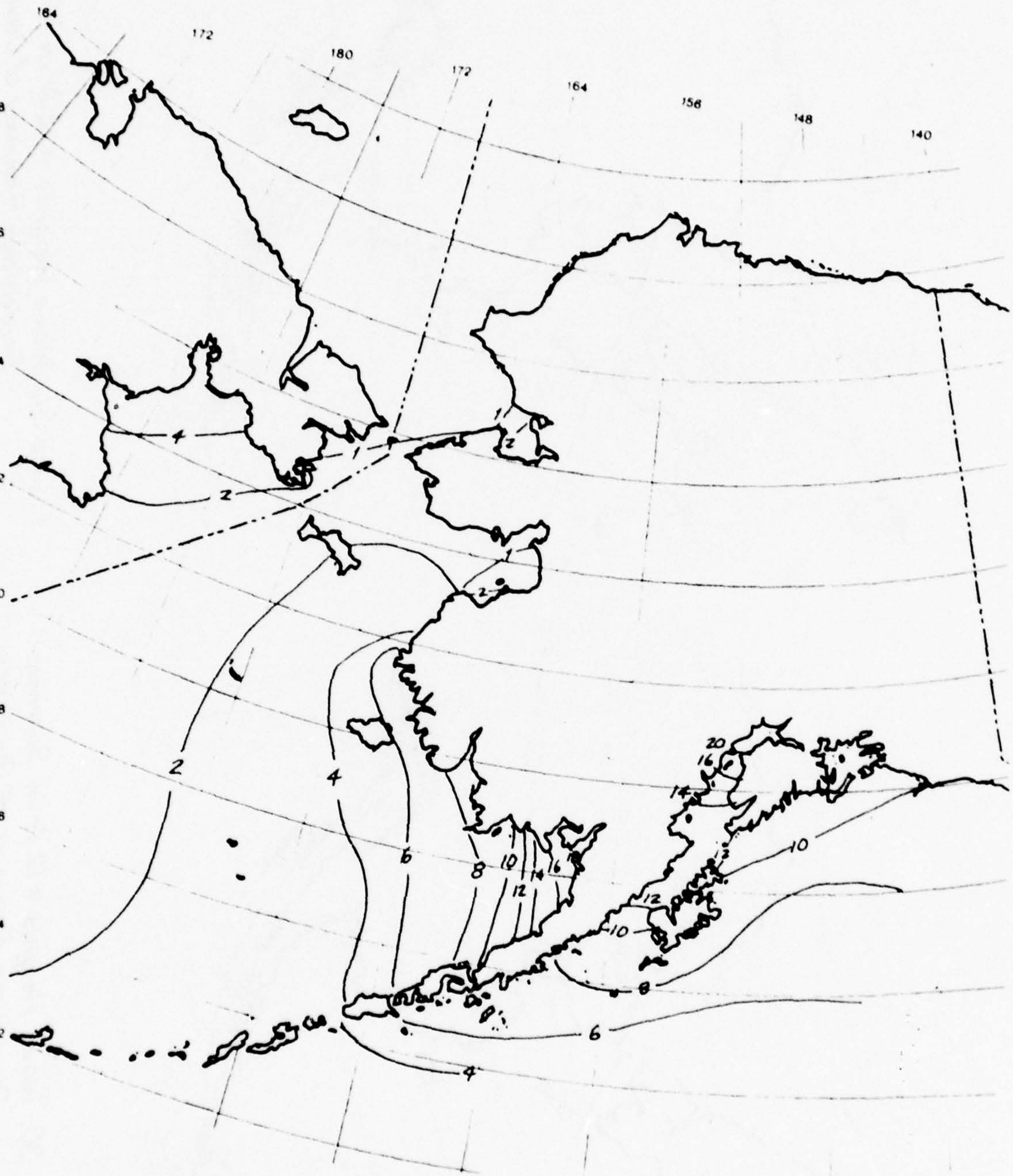


Figure 32. Lines of Tidal Range in Feet

Most of Alaska has two tides per day, however, in the Bering Sea from Dutch Harbor north, diurnal tides having a single high and low tide are normal during parts or all of a month. Bristol Bay, with its very high tidal range, is an exception to this having two tides per day. Tides can also be affected by winds and storm surges with the result being water level variations in excess of the purely tidal variations shown in Figure 32. The very high tidal range in Cook Inlet and Bristol Bay results in strong tidal currents in these areas. Strong tidal currents have also been measured in the passes through the eastern Aleutian Islands. The great tidal variation in Cook Inlet proves to be an advantage in some ways, since, without this tidal variation, a solid sheet of ice would form at freezeup in the fall and remain in place until breakup in the spring. Because of the tidal action and tidal currents, the ice in Cook Inlet is generally maintained in a broken condition. The narrowest point of Cook Inlet between the east and west forelands has recorded midchannel tidal currents of 1 to 6 knots.

Water Temperatures

Summer and winter Alaskan sea water temperatures are shown in Figures 33 and 34 respectively [9, 11, 12]. The relatively warm summer water temperatures in the Gulf of Alaska result from the warm Alaskan current which flows northward from southeastern Alaska. The warm waters of the Bering Sea are carried northward by currents through the Bering Strait into the Chukchi Sea. Summer warming trends are particularly pronounced in protected shallow areas such as Norton Sound and Kotzebue Sound where summer sea temperatures rise to above 50°F. Along the north coast, however, summer water temperatures remain near 32°F as a result of the limited 3 to 4 month ice free period and the near proximity of polar pack ice. Little opportunity therefore exists for any significant change in water temperature along Alaska's northern coast. During the winter, the Alaska current maintains the southern Alaska coast ice free except in regions of protected waters such as upper Cook Inlet. The temperature of water beneath sea ice will be at the freezing point of sea water, 28°F.

Light

The daily period of sunlight varies rapidly throughout the year in Alaska except for periods when the days are the longest and the shortest. The change is greatest in the more northern latitudes where, for example, at Point Barrow the amount of daily daylight varies from complete darkness to continuous daylight in less than 4 months. Figures 35, 36, and 37 summarize sunlight hours in northern latitudes, twilight hours in northern latitudes, and sunlight plus twilight hours in northern latitudes as presented in the Environmental Atlas of Alaska [9]. Twilight is defined as that period when the sun is below the horizon but not more than 6° below the horizon. While some are of the opinion that most outdoor activities can be carried on during this period without artificial lighting, particularly in snow covered areas where maximum use is made of available light, others have disagreed with this opinion. It is therefore conservatively assumed in this study that only the sunlight period is appropriate for successfully carrying out outdooor activities without artificial lighting. Figure 35 shows that the period of continuous daylight in northern Alaska centers on June 21 and extends for a period of about 2.5 months, from mid-May through the end of July, at Point Barrow.

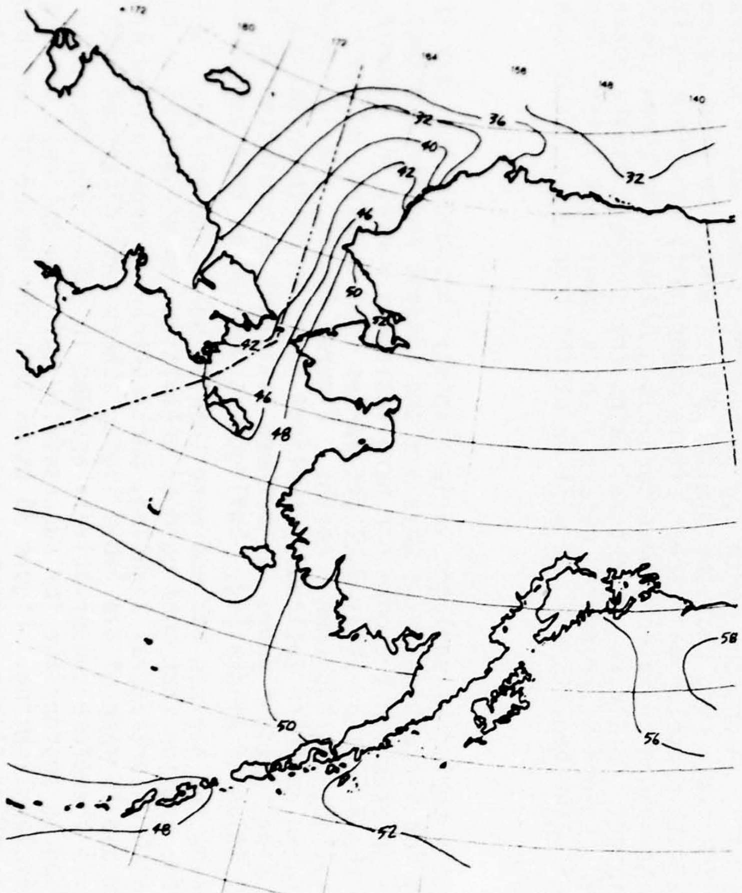


Figure 33. Summer Sea Temperatures off Alaska, °F

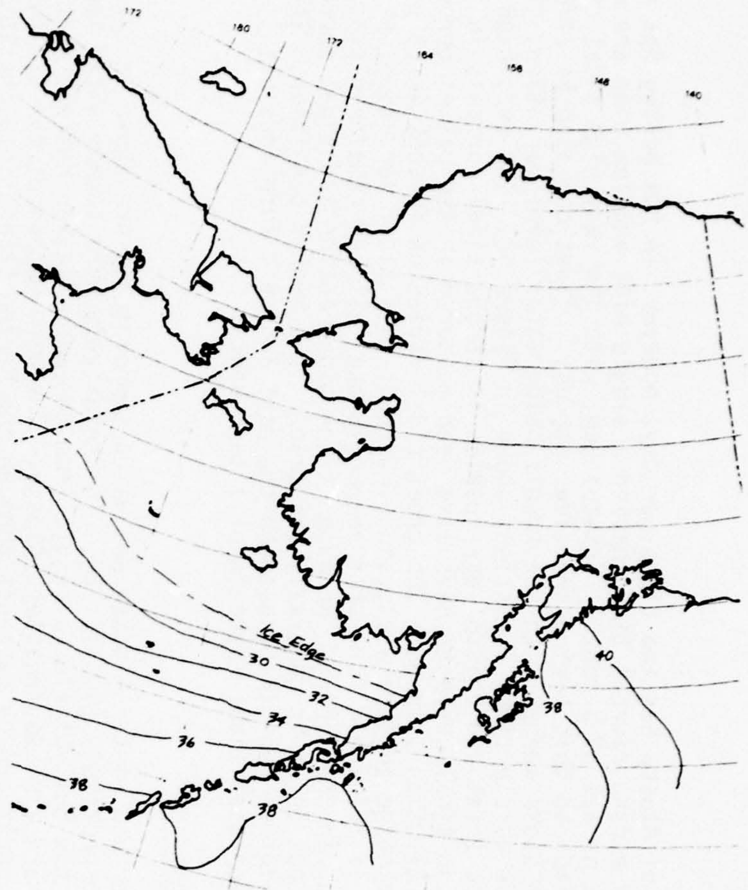


Figure 34. Winter Sea Temperatures off Alaska, °F

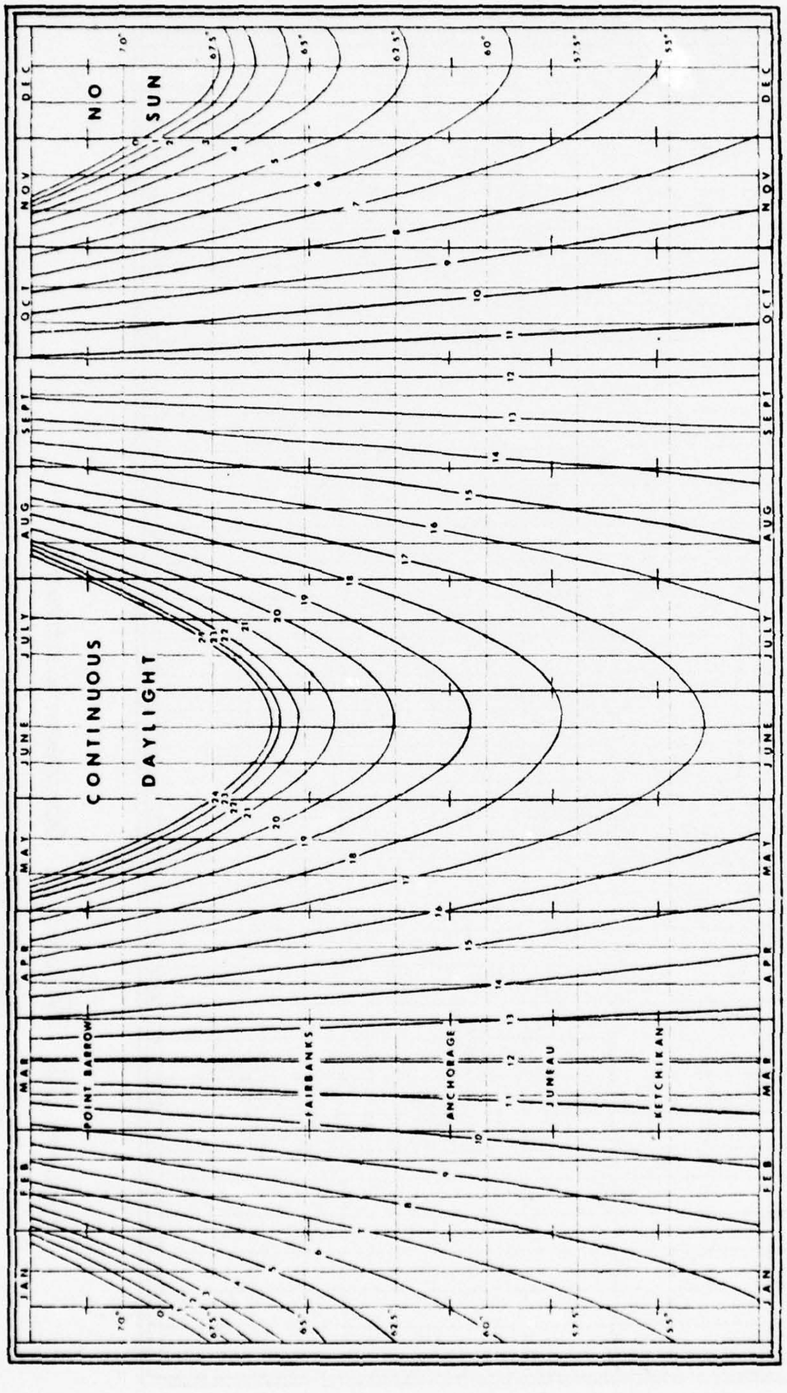


Figure 35. Sunlight in Northern Latitudes

Copyrighted by University of Alaska, Reprinted by Permission

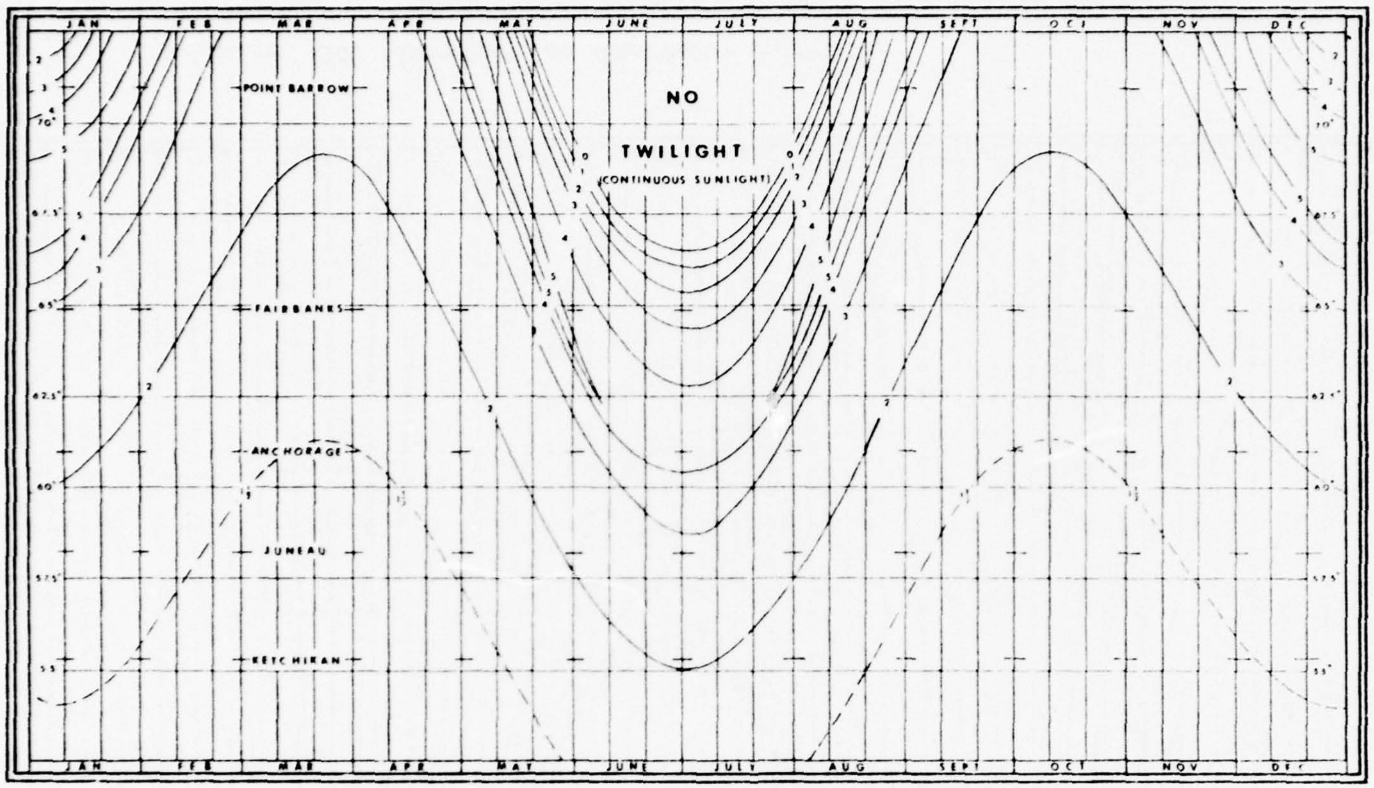


Figure 36. Twilight in Northern Latitudes

Copyrighted by University of Alaska, Reprinted by Permission

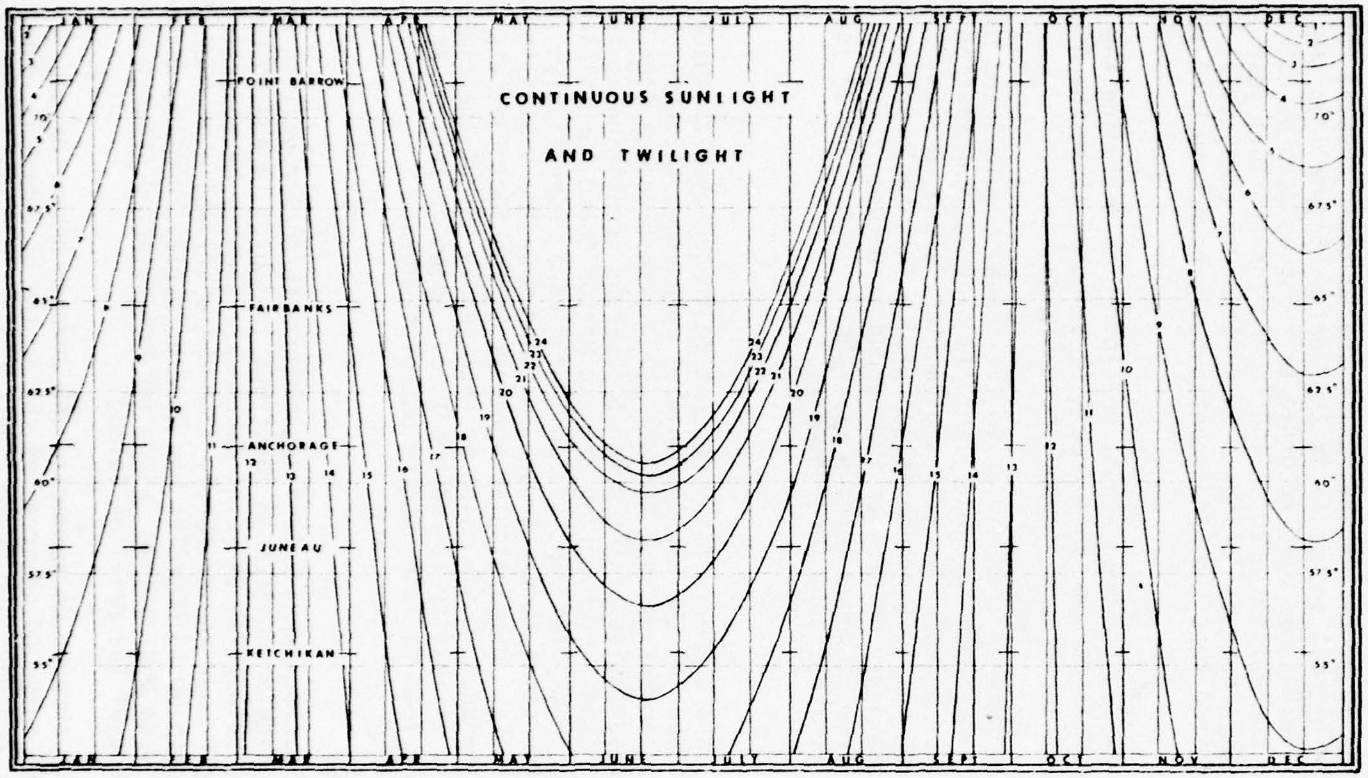


Figure 37. Sunlight Plus Twilight in Northern Latitudes

Copyrighted by University of Alaska, Reprinted by Permission

Precipitation

The mean annual snowfall distribution and the mean annual precipitation distribution are shown in Figures 38 and 39 respectively [13]. Snowfall is relatively limited in arctic Alaska, while the southern coastal regions experience some of the highest snowfalls in the world. Snowfall in the Thompson Pass region near Valdez has been recorded to reach as much as 225 inches in a single month, in comparison to 20 to 100 inches for the full year in the northern and western coastal regions. In addition to the initial snowfall, it must be recognized that the winds continuously rework much of the snow into drifts.

From Figure 39, the mean annual precipitation including the water equivalent of snow is seen to vary from 4 to 5 inches along the Arctic coast to over 200 inches in parts of southeastern Alaska.

Also of importance in addition to the annual snowfall and precipitation, is the depth of snow on the ground. Table 12 provides information of this nature for the five selected locations of Barter Island, Barrow, Kotzebue, Nome, and Northeast Cape on St. Lawrence Island [13]. This table shows, for example, that at Barrow the depth of snow on the ground is between 7 and 12 inches about 50% of the time from December through May, and is from 13 to 24 inches in depth 50% of the time from February through April.

Visibility

Table 13 is a summary of the percentage frequency with which obstructions to vision occur at the six communities of Barrow, Kotzebue, Nome, Pribilof Islands, Anchorage, and Kodiak [13]. These communities were selected as representative of the geographic areas identified as the North Slope, Kotzebue Sound, North Bering Sea and Norton Sound, South Bering Sea and Bristol Bay, Cook Inlet, and the Gulf of Alaska respectively. By definition, obstructions to vision are recorded when the visibility is reduced to six miles or less. Of particular interest is the fact that visibility at Point Barrow is reduced to six miles or less nearly 25% of the time. In contrast to this, visibility is reduced to six miles or less at Anchorage only 4% of the time or less for nine months out of the year.

Wind and Storms

Mean and maximum wind velocities along with the prevailing wind direction are presented for selected Alaskan locations in Tables 14 and 15 respectively [14]. Mean wind velocities at Point Barrow are seen to be moderate at 10 to 13 miles per hour and primarily from the east, while maximum wind velocities approach 50 to 60 miles per hour primarily from the north-northeast. The most severe mean and maximum winds for the selected areas is seen to be at St. Paul Island of the Pribilof Islands.

Figures 40 through 45 summarize the average number of storms per month in Alaska and the surrounding area for the months of February, April, June, August, October, and December respectively [13]. In general, the northern

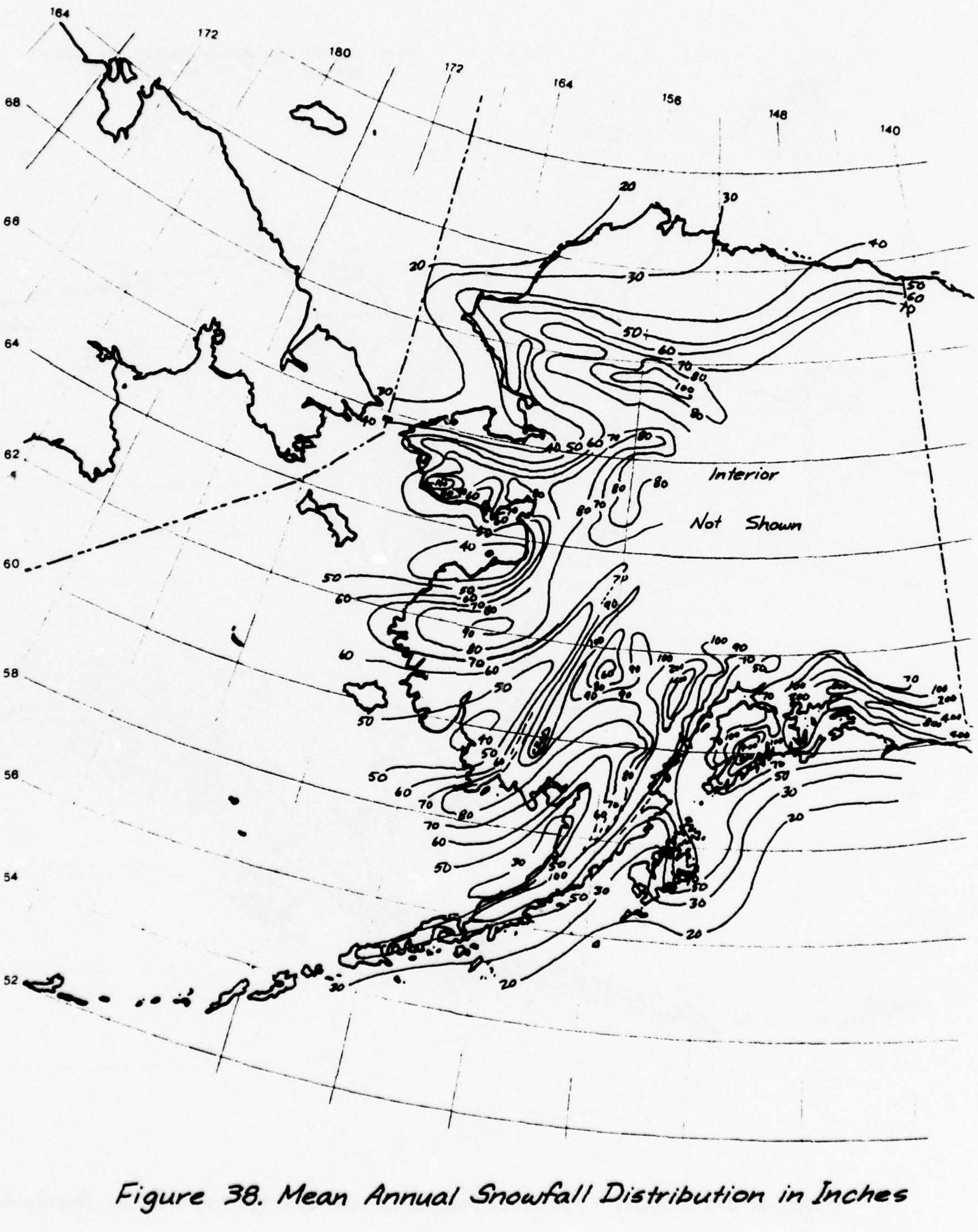


Figure 38. Mean Annual Snowfall Distribution in Inches

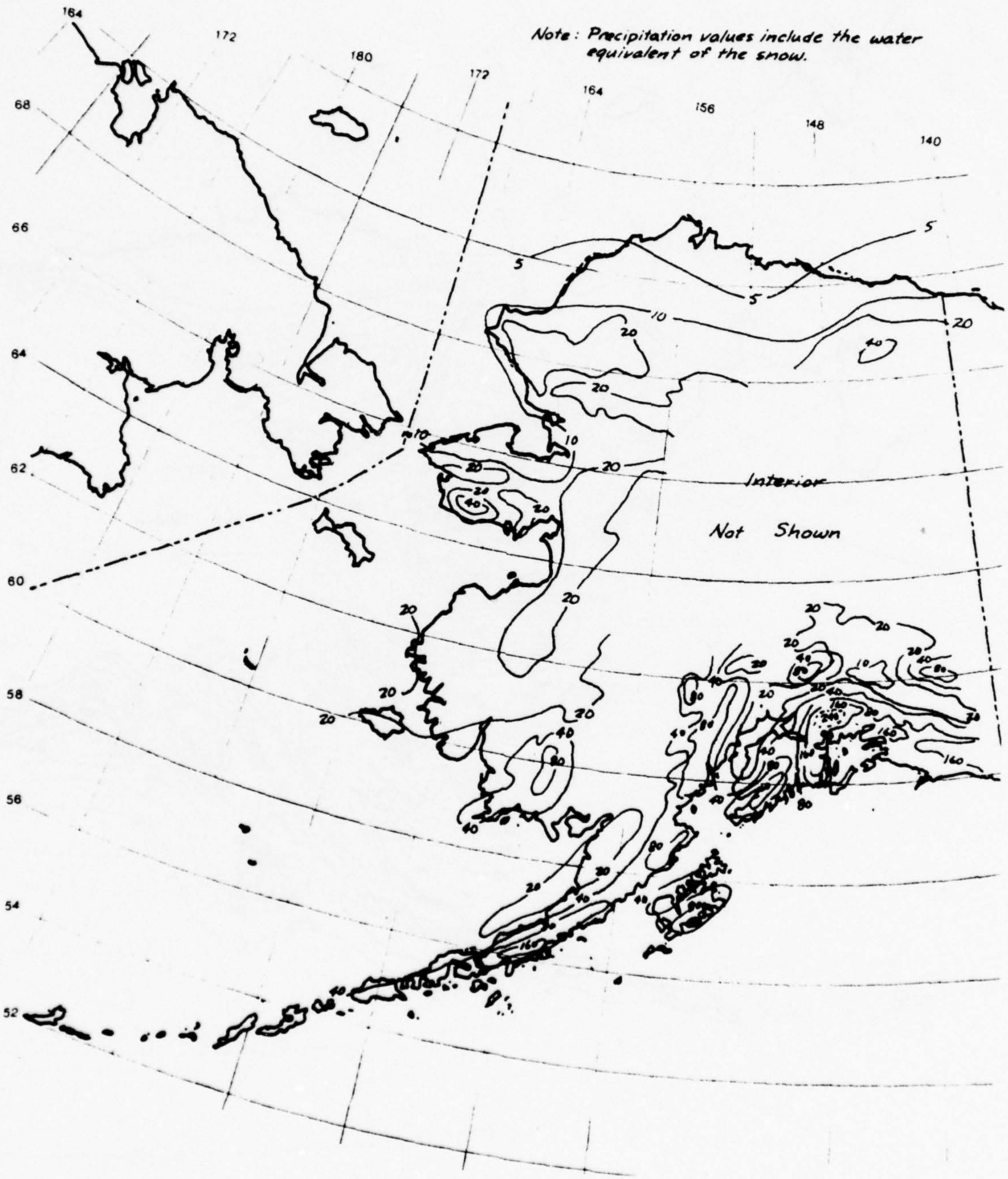


Figure 39. Mean Annual Precipitation Distribution in Inches

TABLE 12. DEPTH OF SNOW ON GROUND
(Percentage Frequency of Occurrence)

	None or Trace	1-3 inches	4-6 inches	7-12 inches	13-24 inches	25-36 inches	37-48 inches
BARTER ISLAND							
January	0	0	9	31	37	21	2
February	0	0	2	17	56	18	7
March	0	0	1	19	47	20	13
April	0	0	6	29	29	26	10
May	0	8	14	25	38	13	2
June	49	26	7	10	6	2	0
July	99	1	0	0	0	0	0
August	98	2	0	0	0	0	0
September	78	15	2	2	3	0	0
October	18	20	34	20	8	0	0
November	0	4	26	46	24	0	0
December	0	0	16	40	35	9	0
BARROW							
January	0	0	20	55	25	0	0
February	0	0	2	48	50	0	0
March	0	0	0	50	50	0	0
April	0	0	0	50	50	0	0
May	0	1	14	55	30	0	0
June	51	30	6	11	2	0	0
July	94	6	0	0	0	0	0
August	90	10	0	0	0	0	0
September	52	38	10	0	0	0	0
October	12	51	24	13	0	0	0
November	0	9	44	43	4	0	0
December	0	0	33	57	10	0	0
KOTZEBUE							
January	0	1	1	48	46	3	0
February	0	2	2	19	60	17	0
March	0	0	4	7	67	22	0
April	0	2	4	12	60	18	4
May	28	13	12	16	27	4	0
June	91	6	3	1	0	0	0
July	100	0	0	0	0	0	0
August	100	0	0	0	0	0	0
September	98	2	0	0	0	0	0
October	58	25	12	5	0	0	0
November	2	29	40	23	6	0	0
December	0	4	20	50	26	0	0

TABLE 12. DEPTH OF SNOW ON GROUND (Continued)
(Percentage Frequency of Occurrence)

	None or Trace	1-3 inches	4-6 inches	7-12 inches	13-24 inches	25-36 inches	37-48 inches
NOME							
January	2	4	5	25	44	15	5
February	3	5	4	14	41	26	7
March	1	5	1	19	29	45	1
April	1	6	9	12	35	32	4
May	40	19	12	12	9	7	0
June	98	2	0	0	0	0	0
July	100	0	0	0	0	0	0
August	100	0	0	0	0	0	0
September	99	1	0	0	0	0	0
October	72	19	6	2	0	0	0
November	16	35	23	20	6	1	0
December	2	8	23	40	18	8	0
NORTHEAST CAPE							
January	0	0	7	38	39	16	0
February	0	0	0	33	54	8	5
March	0	0	5	28	40	27	0
April	0	10	1	6	34	46	4
May	9	16	11	20	33	11	0
June	80	15	4	1	0	0	0
July	100	0	0	0	0	0	0
August	100	0	0	0	0	0	0
September	100	0	0	0	0	0	0
October	59	31	9	0	0	0	0
November	5	28	39	27	1	0	0
December	0	4	25	44	25	1	0

TABLE 13. PERCENTAGE FREQUENCY OF OCCURRENCE OF OBSTRUCTIONS TO VISION AND DAYS WITH HEAVY FOG

	Month	Fog	Blowing Snow	Smoke And/Or Haze	Percentage Observations With Obstructions To Vision		Days With Heavy Fog
POINT BARROW	January	12.5	13.7	0.5	24.7		2
	February	13.1	12.6	0.3	25.3		2
	March	7.9	10.0	0.2	17.3		1
	April	9.3	7.8	0.2	16.7		3
	May	17.4	4.0	0.0	21.0		8
	June	26.4	0.5	0.0	26.9		12
	July	25.9	0.0	0.0	25.9		13
	August	25.5	0.0	0.0	25.5		12
	September	17.7	0.7	0.0	18.2		5
	October	13.0	7.7	0.0	20.9		4
	November	10.5	16.3	0.0	26.0		3
	December	10.4	13.5	0.1	22.5		2
	Average	15.8	7.2	0.1	22.6	Total	65
KOTZEBUE	January	5.0	12.0	0.0	17.0		1
	February	7.0	12.0	0.0	18.0		1
	March	6.0	9.0	0.0	14.0		1
	April	7.0	6.0	0.0	12.0		2
	May	7.0	1.0	0.0	8.0		3
	June	10.0	0.0	0.0	10.0		5
	July	5.0	0.0	0.6	6.0		2
	August	5.0	0.0	0.3	5.0		1
	September	3.0	0.0	0.1	3.0		1
	October	3.0	2.0	0.0	5.0		1
	November	4.0	7.0	0.1	11.0		1
	December	5.0	8.0	0.0	13.0		1
	Average	6.0	5.0	0.1	10.0	Total	19

Note: Obstructions to vision are recorded when the visibility is reduced to 6 miles or less. The statistics for fog were compiled by noting the occurrence of heavy fog on a daily rather than hourly basis. Heavy fog, defined as fog reducing visibility to 1/4 mile or less, must occur at some time during a day to establish a day with heavy fog.

TABLE 13. PERCENTAGE FREQUENCY OF OCCURRENCE OF OBSTRUCTIONS TO VISION AND DAYS WITH HEAVY FOG (Continued)

	Month	Fog	Blowing Snow	Smoke And/Or Haze	Percentage Observations With Obstructions To Vision		Days With Heavy Fog
NOME	January	10.0	7.0	0.0	17.0		2
	February	7.0	6.0	0.0	12.0		1
	March	8.0	5.0	0.0	13.0		2
	April	11.0	3.0	0.0	13.0		1
	May	12.0	0.0	0.0	12.0		4
	June	15.0	0.0	0.3	16.0		4
	July	20.0	0.0	0.4	21.0		4
	August	20.0	0.0	0.3	20.0		2
	September	10.0	0.0	0.0	10.0		1
	October	5.0	1.0	0.0	7.0		0
	November	7.0	4.0	0.0	11.0		1
	December	7.0	5.0	0.0	12.0		2
	Average	11.0	3.0	0.1	14.0	Total	17
PRIBILOF ISLANDS	January	17.5	7.2	No Data	No Data		No Data
	February	17.8	13.2				
	March	16.2	10.7				
	April	18.5	4.4				
	May	30.0	0.4				
	June	40.8	0.0				
	July	56.1	0.0				
	August	43.6	0.0				
	September	23.8	0.0				
	October	8.5	0.0				
	November	10.9	0.0				
	December	20.9	1.3				
	Average	24.6	6.3				

TABLE 13. PERCENTAGE FREQUENCY OF OCCURRENCE OF OBSTRUCTIONS TO VISION AND DAYS WITH HEAVY FOG (Continued)

	Month	Fog	Blowing Snow	Smoke And/Or Haze	Percentage Observations With Obstructions To Vision	Days With Heavy Fog
ANCHORAGE	January	12.8	0.1	0.0	13.0	No Data
	Febuary	7.1	0.0	0.0	7.2	
	March	2.4	0.0	0.0	2.4	
	April	2.3	0.0	0.0	2.3	
	May	0.3	0.0	0.0	0.3	
	June	1.1	0.0	0.1	1.2	
	July	1.9	0.0	0.8	2.7	
	August	1.9	0.0	0.0	1.9	
	September	3.1	0.0	0.0	3.1	
	October	2.6	0.0	0.3	2.9	
	November	4.3	0.1	0.0	4.4	
	December	7.8	0.1	0.1	7.9	
	Averarage	4.0	0.0	0.1	4.1	
KODIAK	January	8.7	2.4	0.0	11.1	No Data
	February	8.3	1.4	0.0	9.7	
	March	5.4	2.9	0.0	8.3	
	April	6.1	0.4	0.0	6.6	
	May	12.2	0.0	0.0	12.2	
	June	16.4	0.0	0.1	16.5	
	July	17.1	0.0	0.4	17.5	
	August	12.8	0.0	0.0	12.9	
	September	10.5	0.0	0.0	10.5	
	October	6.1	0.0	0.1	6.3	
	November	8.2	1.2	0.0	9.3	
	December	6.1	2.6	0.0	8.7	
	Average	9.8	0.9	0.1	10.8	

TABLE 14. MEAN WIND VELOCITIES (MPH) AND PREVAILING DIRECTION

	POINT BARROW		KOTZEBUE		NOME	
	Velocity	Direction	Velocity	Direction	Velocity	Direction
January	11.3	ESE	14.6	E	11.7	E
February	10.9	E	12.9	E	11.3	NE
March	11.2	ENE	12.5	E	10.4	E
April	11.5	NE	12.9	ESE	10.9	N
May	11.6	ENE	10.8	W	10.4	N
June	11.4	E	12.2	W	10.1	WSW
July	11.5	E	12.9	W	10.1	WSW
August	12.4	E	13.3	W	10.7	SW
September	13.1	E	13.0	E	11.3	N
October	13.3	E	13.5	ENE	11.4	N
November	12.6	E	14.4	E	12.2	N
December	11.2	E	12.6	NE	10.3	E

	PRIBILOF ISLANDS (ST. PAUL ISLAND)		KODIAK		ANCHORAGE	
	Velocity	Direction	Velocity	Direction	Velocity	Direction
January	20.8	E	12.4	Not Given	5.8	NNE
February	21.8	N	11.7	Not Given	6.4	N
March	20.1	S	11.9	Not Given	6.7	N
April	19.2	NW	10.9	Not Given	7.1	N
May	16.2	Not Given	9.9	Not Given	8.3	S
June	14.3	Not Given	8.3	Not Given	8.1	S
July	12.9	Not Given	6.7	Not Given	7.1	S
August	14.8	Not Given	7.5	Not Given	6.6	S
September	16.2	Not Given	8.9	Not Given	6.0	NNE
October	19.4	Not Given	10.7	Not Given	6.3	N
November	22.7	Not Given	12.1	Not Given	6.0	NNE
December	22.3	Not Given	12.1	Not Given	5.9	NNE

TABLE 14. MEAN WIND VELOCITIES (MPH) AND PREVAILING DIRECTION (CONTINUED)

	KING SALMON		COLD BAY		BARTER ISLAND	
	Velocity	Direction	Velocity	Direction	Velocity	Direction
January	10.4	N	17.8	SSE	14.8	W
February	11.3	N	18.0	SSE	14.2	W
March	11.6	N	17.4	NNW	13.7	W
April	11.2	NNW	18.2	SSE	11.9	W
May	11.4	S	16.4	SSE	12.5	E
June	10.8	SW	15.9	WNW	11.5	ENE
July	10.1	S	15.7	SSE	10.6	E
August	10.3	S	16.5	SSE	11.7	E
September	10.6	S	16.3	SSE	13.1	E
October	10.6	N	16.9	WSW	14.6	E
November	10.9	N	17.5	SSE	15.0	E
December	10.4	N	16.8	NNW	13.9	E

	UNALAKLEET	
	Velocity	Direction
January	18.0	ENE
February	14.4	ENE
March	17.2	ENE
April	12.6	ENE
May	12.0	ENE
June	10.4	W
July	10.7	W
August	14.0	NE
September	12.3	ENE
October	13.4	ENE
November	17.1	ENE
December	15.8	ENE

TABLE 15. MAXIMUM WIND VELOCITIES (MPH) AND PREVAILING DIRECTION

	POINT BARROW		KOTZEBUE		NOME	
	Velocity	Direction	Velocity	Direction	Velocity	Direction
January	49	N-NNE	64	N-NNE	54	N-NNE
February	48	N-NNE	93	N-NNE	51	N-NNE
March	58	NNE-NE	55	N-NNE	44	N-NNE
April	40	NNE-NE	62	N-NNE	45	N-NNE
May	39	NNE-NE	40	NNE-NE	44	N-NNE
June	35	NNE	42	NNE-NE	35	N-NNE
July	35	NNE	51	N-NNE	35	NNE-NE
August	36	NNE	49	NNE-NE	40	NNE-NE
September	44	NNE-NE	52	NNE-NE	44	N-NNE
October	55	NNE-NE	47	N-NNE	52	N-NNE
November	54	NNE-NE	88	N-NNE	55	NNE-NE
December	55	NNE-NE	66	N-NNE	54	N-NNE

	PRIBILOF ISLANDS (ST. PAUL ISLAND)		KODIAK		ANCHORAGE	
	Velocity	Direction	Velocity	Direction	Velocity	Direction
January	63	N-NNE	55	NW	61	N
February	69	N-NNE	48	NW	44	N
March	72	N-NNE	40	NW	35	N
April	51	N-NNE	41	N	35	NNE
May	46	NNE-NE	39	N	33	N
June	44	N-NNE	35	N	30	NNE
July	39	N-NNE	32	N	29	NNE
August	46	N-NNE	45	N	30	NNE
September	53	N-NNE	44	N	33	NNE
October	60	NNE-NE	42	N	40	N
November	82	NNE-NE	53	N	37	N
December	62	NNE-NE	50	NNE	41	N

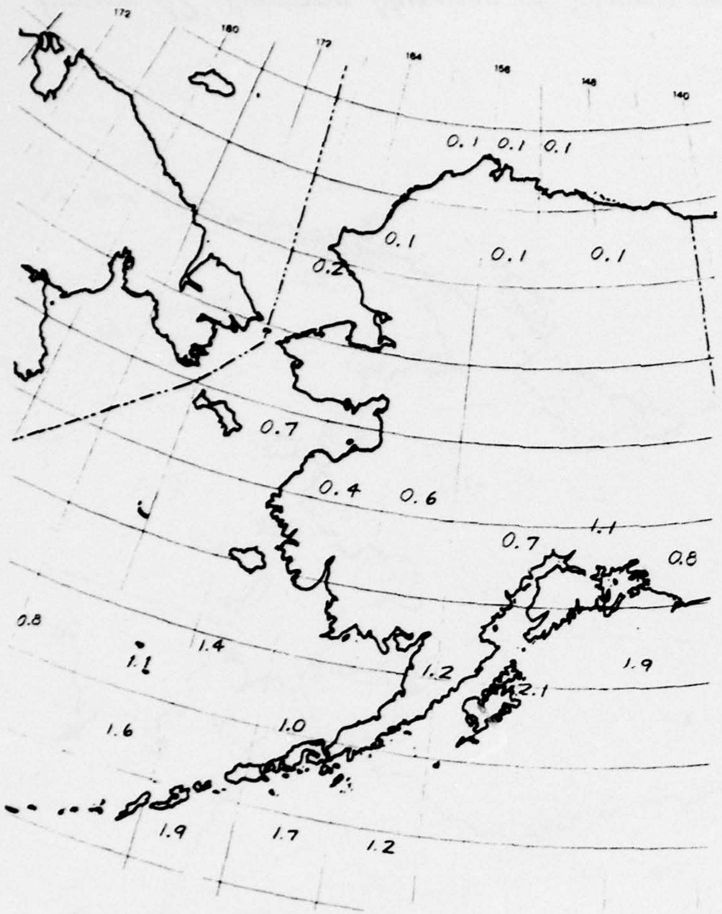


Figure 40. Average Number of Storms per Month for February

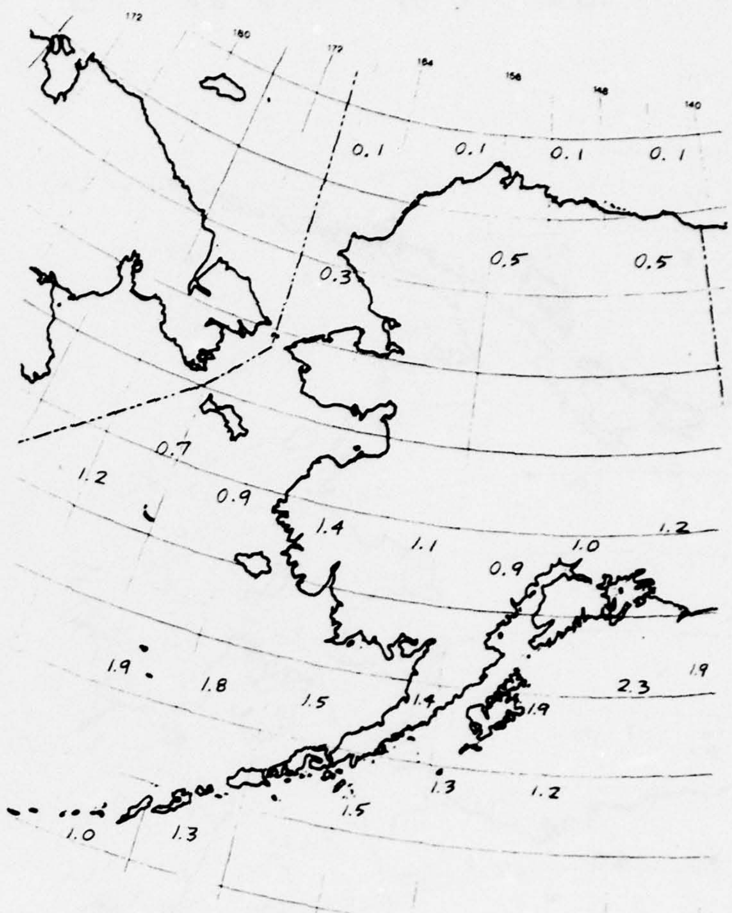


Figure 41. Average Number of Storms per Month for April

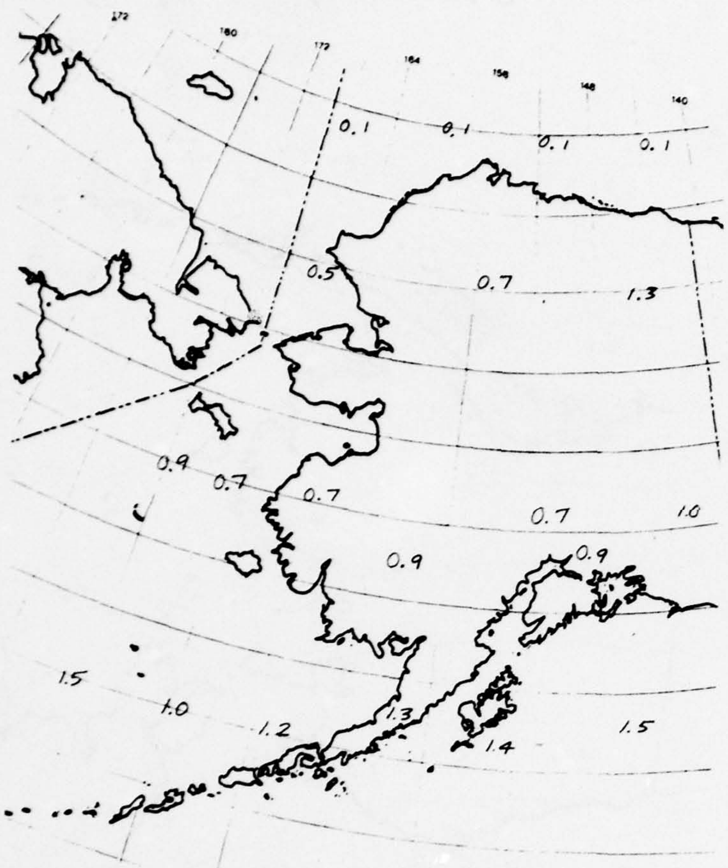


Figure 42. Average Number of Storms per Month for June

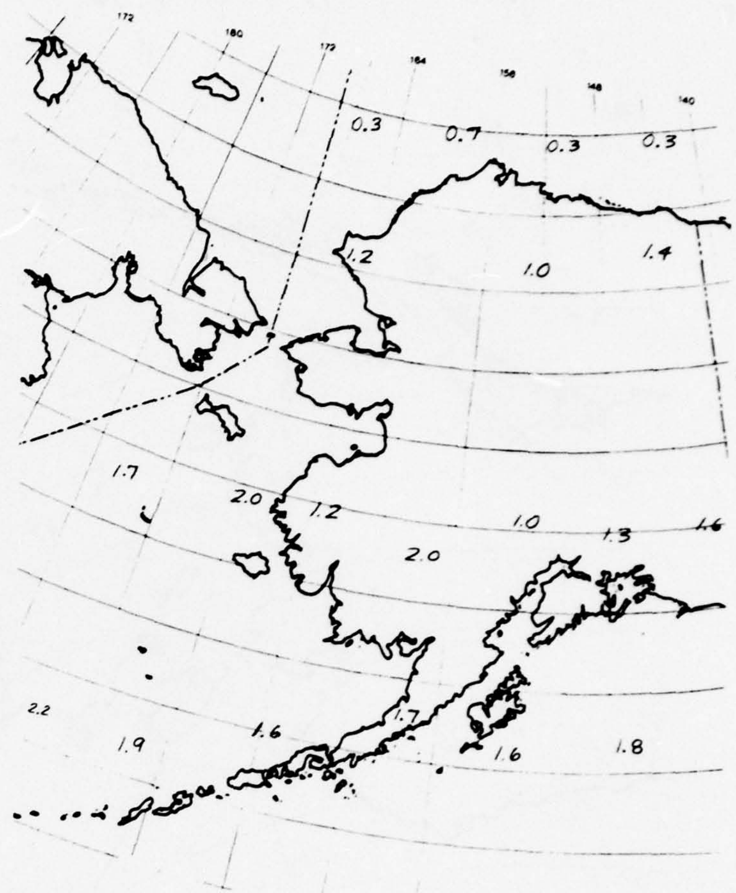


Figure 43. Average Number of Storms per Month for August

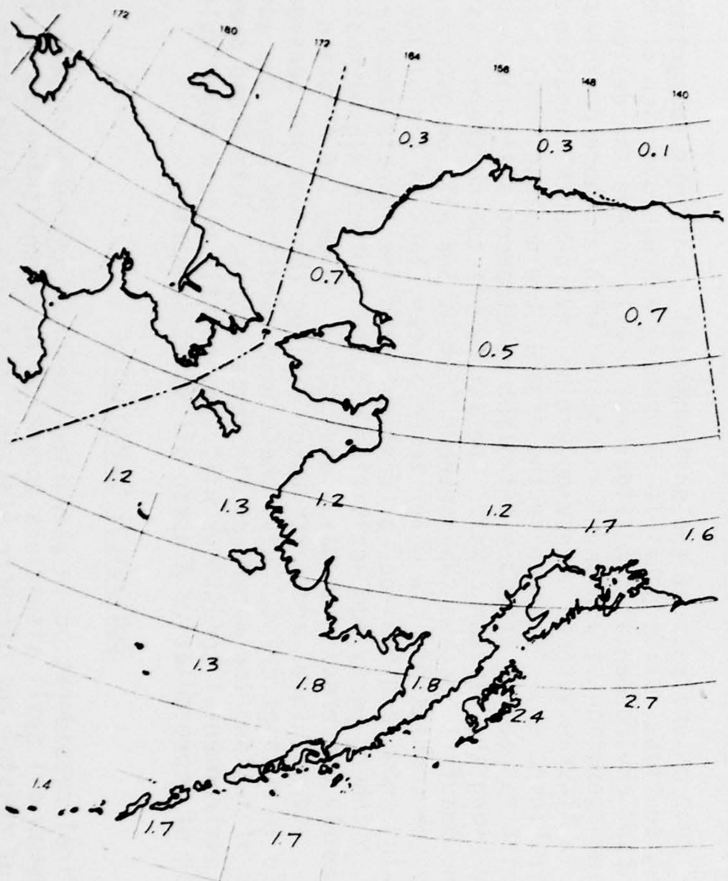


Figure 44. Average Number of Storms per Month for October.

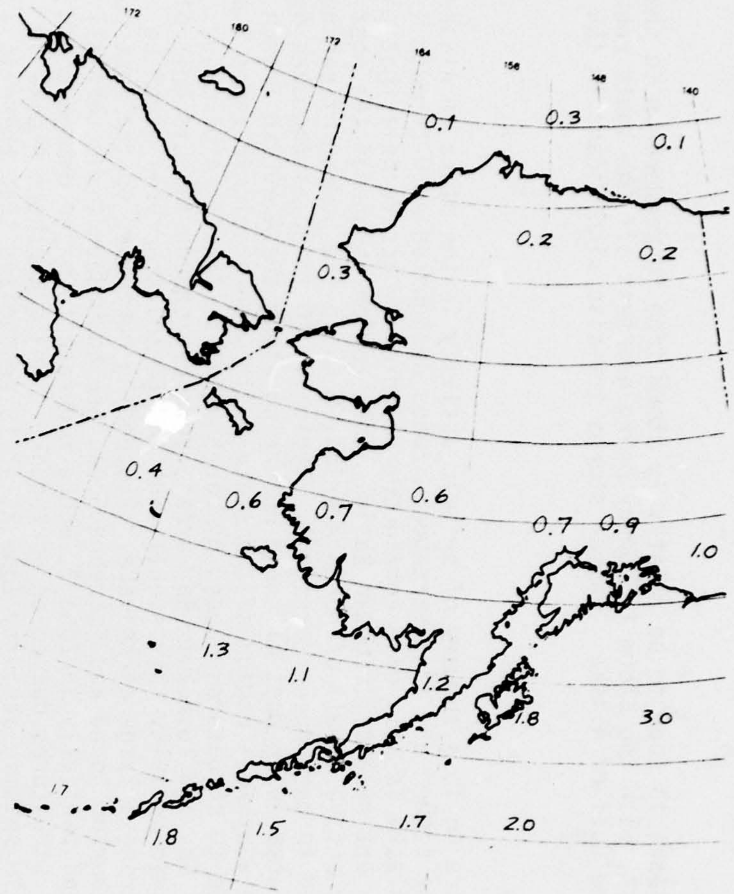


Figure 45. Average Number of Storms per Month for December

coast of Alaska is seen to be relatively storm free in comparison to the rest of the coast, with the storm frequency being greatest off the south central coast in the Gulf of Alaska. Summer storms are also significant in the central Bering Sea.

Earthquakes

Figure 46 is a summary of seismic activity in the state of Alaska [13]. Shown on the figure are five earthquake zones designated as 0 through 4. Southwest Alaska is part of a continuous seismically active belt that circumscribes the entire Pacific Ocean Basin. This region is one of the most seismically active in all of North America, both in the number of earthquakes recorded and in earthquake magnitude. Typically 10 to 20 earthquakes occur daily in Alaska, with most of these occurring along the Aleutian Trench. Much of the southwest region of the state falls within seismic zones 3 and 4 where damage to structures caused by earthquakes is likely to be major. The Bristol Bay and Kuskokwim Bay areas are close enough to this belt of severe seismic activity that significant damage to structures might be expected during a large earthquake. Proceeding northward up the west coast of Alaska, Norton Sound and Kotzebue Sound are both seen to be partially in Zone 2 and partially in Zone 3, where moderate to major damage could be expected to structures due to an earthquake. While northern Alaska is classified in seismic activity Zone 2, it is recognized that there is a general lack of data in this region.

Summary of Significant Environmental Conditions

Based upon an analysis of the environmental conditions summarized in the preceding sections, it is possible to prepare a broad overview of the most significant environmental conditions which will govern the design, construction, and operation of equipment associated with offshore petroleum development in Alaskan waters. These governing environmental conditions are summarized in Figure 47. As shown in the figure, the dominant environmental conditions with respect to offshore petroleum development activities vary considerably along the Alaskan coast. Operations off the northern coast of Alaska in the Beaufort Sea and the northern Chukchi Sea will be governed primarily by ice conditions, low water temperatures, lack of visibility due to fog, blowing snow, and the lack of daylight, and the low air temperatures. In contrast, offshore petroleum activities off the southern Alaska coast will be primarily concerned with waves and storms. Along the Aleutian Island chain, tides, storms, snow, and earthquakes will be the dominant considerations, while in much of Bristol Bay, these same conditions have the added complication of ice and low water and air temperatures. This broad overview of dominant environmental conditions will subsequently play a major role in the selection of representative Alaskan oil spill scenarios.

Ecological Sensitivity

The final consideration in preparing the broad overview of potential offshore Alaskan oil spill situations consisted of establishing the ecological sensitivity of coastal and offshore Alaksan waters on a relative basis. For the purposes of this study, ecological sensitivity was defined as the vulnerability

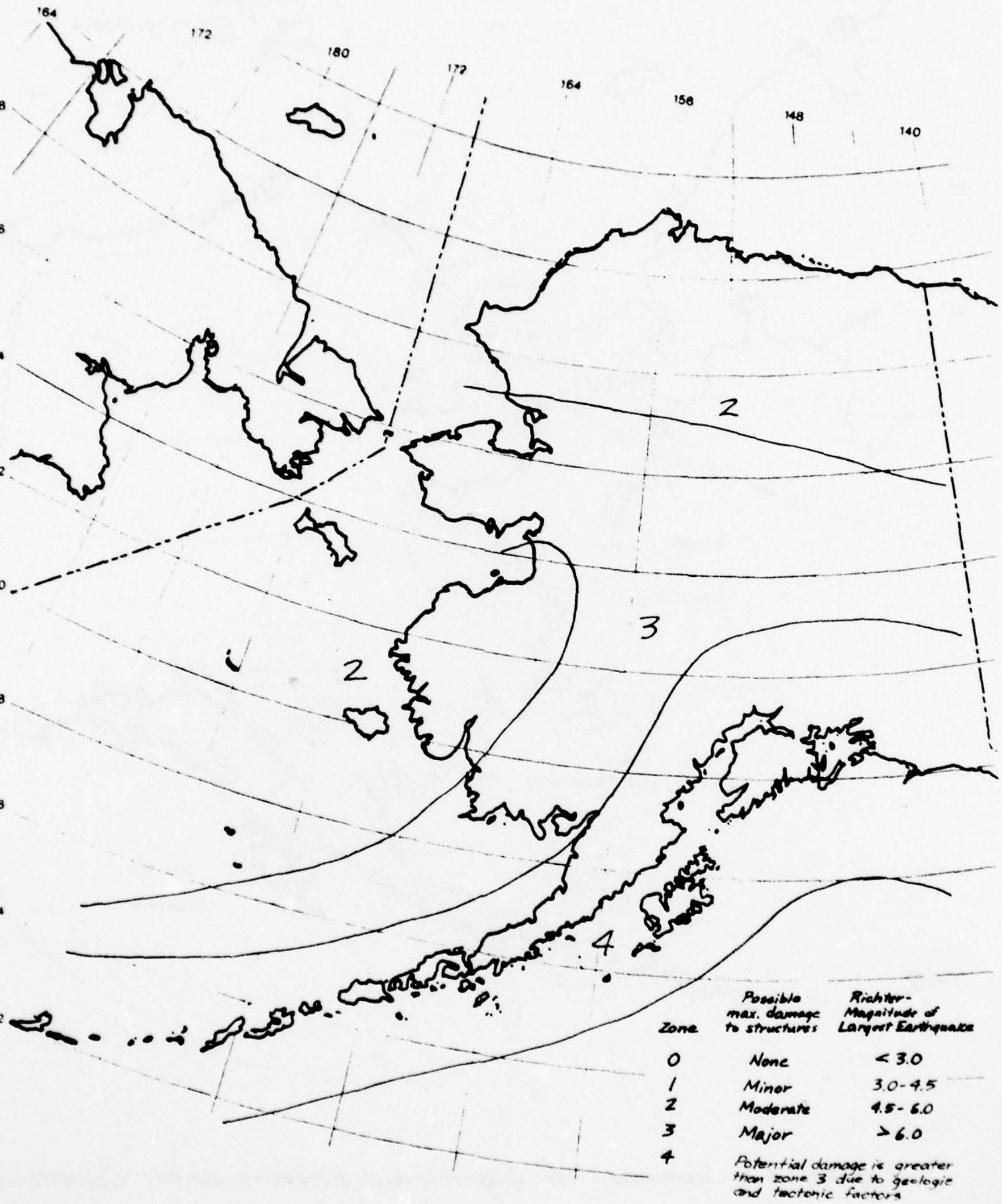


Figure 46. Seismic Zone Map of Alaska

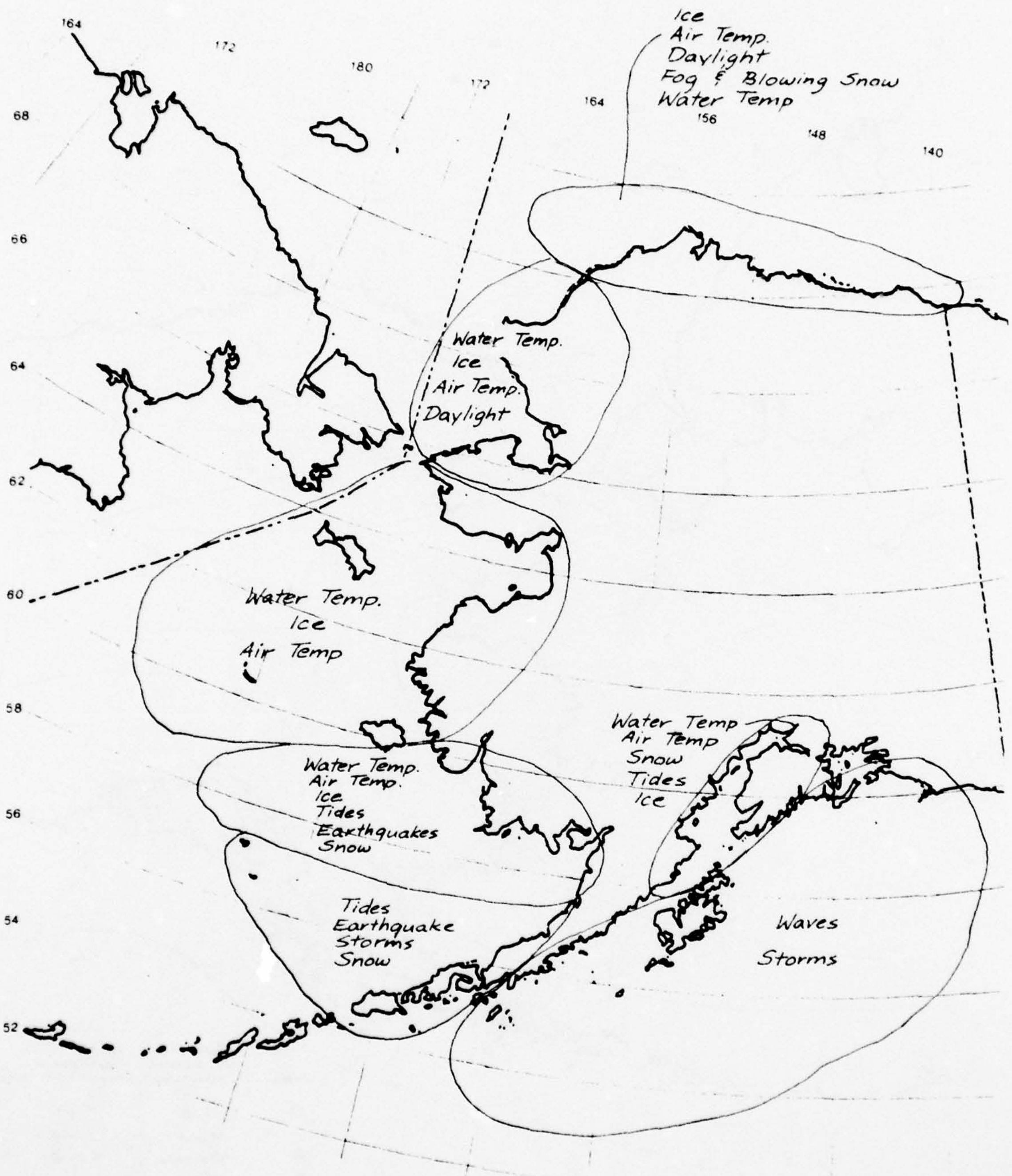


Figure 47. Summary of Significant Environmental Conditions Affecting Offshore Alaskan Petroleum Development Activities

of organisms directly used by the human population for food. The analysis of ecological sensitivity prepared under subcontract by Dr. Eugene H. Buck of the University of Alaska's Arctic Environmental Information and Data Center concentrates on critical points in the life history of the organisms directly used by the human population for food. These critical events are associated with reproduction and early life stages where larvae or eggs are pelagic, planktonic, or occupy inshore areas exposed to the catastrophic effects of an oil spill. In general, the more vulnerable stages would be planktonic stages which have little or no ability to avoid harmful conditions, while the less vunlerable stages would be eggs or larvae of demersal species, and stages which are motile and able to avoid potentially harmful environments. Values of high ecological sensitivity would also result from the occurrence of high concentrations of valued food species. Most vulnerable would be circumstances where all or a majority of a population concentrates in a restricted area. Least vulnerable would be species which very rarely form concentrations or form a number of small concentrations occurring at widely spaced locations.

For the purpose of this study, sport and subsistence uses were considered to be of lesser value than commercial harvest in terms of total volumes of food harvested. In some ways, emphasis on commercial species such as salmon, halibut, herring, and crab account for many of the more important sport and subsistence species. However, north of the Bering Strait, although including St. Lawrence Island, subsistence use of marine mammals and birds was included since the subsistence harvest in most of this area far exceeds the commercial harvest. Not considered in this analysis were minor sport harvests of such species as abalone and sheefish, and subsistence harvests of marine mammals and birds south of the Bering Strait and St. Lawrence Island areas.

Harvest volumes of commercial fish species were utilized to identify the more important species whose life histories would be considered in detail. Commercial species were grouped according to their value as determined by the total volume harvested, and the approximate commercial value per unit weight. Group 1, having the highest value, consisted of pollack and herring. Next in value forming Group 2 were Pacific Ocean perch, flatfish other than halibut, pink salmon, Pacific cod, sockeyed salmon, and king crab. Group 3 consisted of chum salmon, shrimp and tanner crab. Group 4 included halibut, sablefish, coho salmon, and king salmon. The final group, having the lowest value rating, included scallops, snails, Atka mackerel, and Dungeness crab.

The development of the areas of ecological sensitivity proceeded with the preparation of preliminary maps for each species which described where the various important commercial species are found. Seasonal movements between various geographic areas were considered and life histories were researched in order to identify vulnerable concentrations or vulnerable life history events. Areas important to each species were classified for vulnerability on the basis of the degree of concentration and the degree of exposure of reproductive and early life stages. These preliminary maps were then combined into composite maps which included the sensitivity due to a consideration of all species weighted on an arbitrary scale of 1 to 10, where the highest sensitivity value of 10 was given to areas showing the highest combined species value from the initial work maps, and the lowest sensitivity value of 1 was given to those areas showing the lowest combined values recorded from the preliminary species maps. Individual summary maps of ecological sensitivity were then prepared on a monthly basis.

Figures 48 through 59 are the monthly maps of ecological sensitivity developed as a result of the analysis described in the preceding paragraphs. Recognizing that these maps were compiled over a relatively short period of time which did not allow for extensive professional review, it is felt that these maps adequately portray the general patterns of ecological sensitivities with respect to geographic area and time. A bibliography of source material used as the basis for the preparation of the maps of ecological sensitivity is presented in Appendix A. A review of Figures 48 through 59 reveals that in very general terms, the ecology of coastal and offshore Alaska is most sensitive during the spring and summer months. During fall, winter, and early spring, the more sensitive areas are located offshore with a progressive movement towards shore of the more sensitive areas as spring proceeds into summer. During late summer and fall the areas of high ecological sensitivity again decrease in magnitude and recede into the offshore regions. The more sensitive areas are typically found along the edge of the continental shelf and the highly productive inshore fiord and bay systems.

Further analysis of Figures 48 through 59 reveals that the entire northern coast from the Canadian border westward and southward through the Bering Strait to Kotzebue Sound is relatively ecologically insensitive throughout the entire year. Proceeding southward along the western coast of Alaska, this relative ecological insensitivity is seen to extend southward to Bristol Bay from September through April, with the only area of any significant relative sensitivity being near the edge of the Bering Sea shelf to the southwest of the west coast of Alaska. The area along the west coast of Alaska from Kotzebue Sound to Bristol Bay is seen to become relatively sensitive in May, becoming even more sensitive in June, after which it's sensitivity diminishes in July and further diminishes in August and September. The region to the southwest of the west coast of Alaska along the edge of the Bering Sea shelf has regions of relatively high ecological sensitivity from the months of December through May. The area having the greatest year-round ecological sensitivity is seen to be the coastal and offshore area along the southern coast of Alaska and extending along the Aleutian Island chain to a little beyond the Unimak Pass area. The southern coast of Alaska and the waters bordering the Aleutian Islands to just beyond Unimak Pass are seen to be areas of high ecological sensitivity for the months of February through August.

Figure 60 is a broad overview of the relative ecological sensitivity of Alaskan coastal and offshore regions developed on the basis of the preceding monthly maps of ecological sensitivity. For the purposes of this map, the relatively sensitive areas have been defined as those designated level 6 and above. It is seen that the entire northern and northwestern coast of Alaska is relatively ecologically insensitive from the Canadian border all the way around to Kotzebue Sound. The coastal area from Kotzebue Sound along the west coast of Alaska down to Bristol Bay is seen to be relatively sensitive for the months of May, June and July. The offshore area off the southwestern coast of Alaska along the edge of the Bering Sea shelf is seen to be relatively sensitive for the months of February through June, with small pockets of level 6 sensitivity in the months of December and January. The southern coast of Alaska from Prince William Sound to just beyond Unimak Pass is seen to be relatively sensitive for the months of February through August, while the coastal region to the east of Prince William Sound is relatively sensitive for the months of March through August.

AD-A058 782 ARCTEC INC COLUMBIA MD F/G 13/2
SYSTEMS FOR ARCTIC SPILL RESPONSE. VOLUME I.(U)
MAR 78 L A SCHULTZ, P C DESLAURIERS DOT-CG-71343-A
UNCLASSIFIED 405C-3-VOL-1 USCG-D-44-78-VOL-1 NL

2 OF 4
AD
A058 782

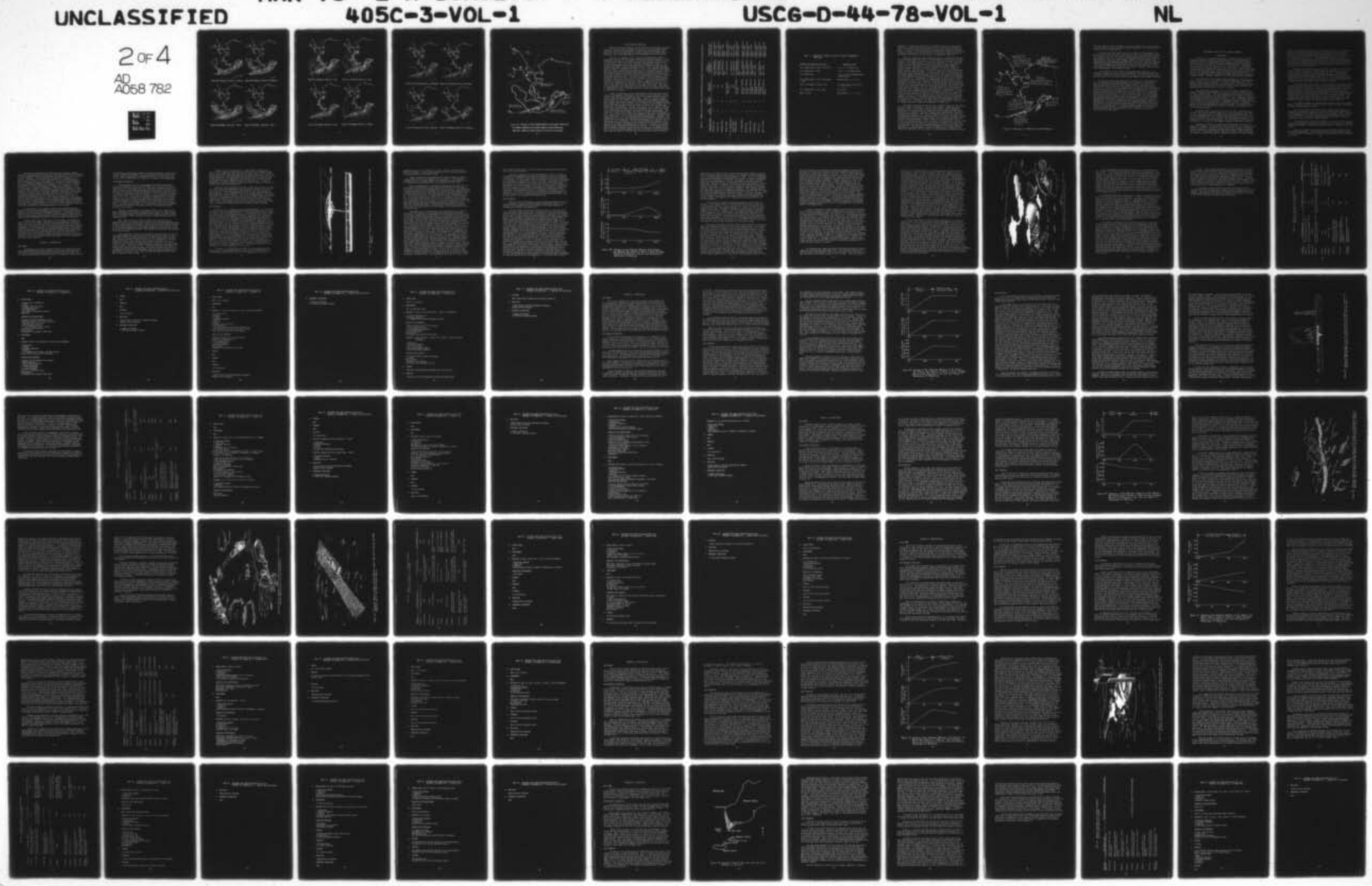


Figure 48. Ecological Sensitivity - January

Figure 49. Ecological Sensitivity - February

Figure 50. Ecological Sensitivity - March

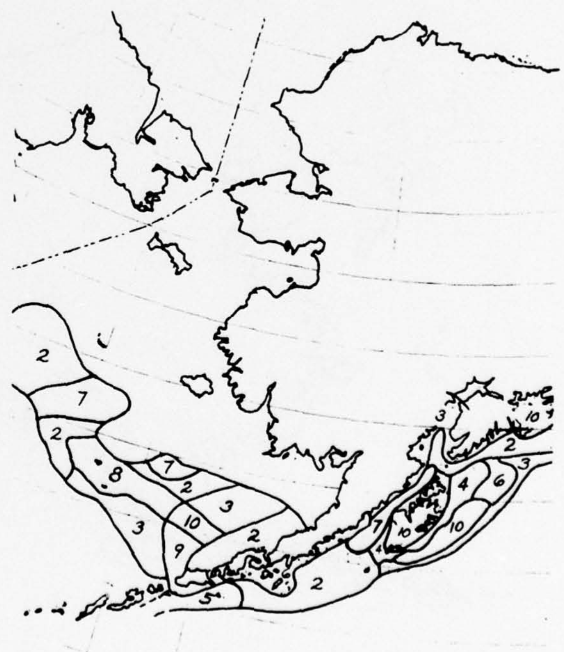


Figure 51. Ecological Sensitivity - April

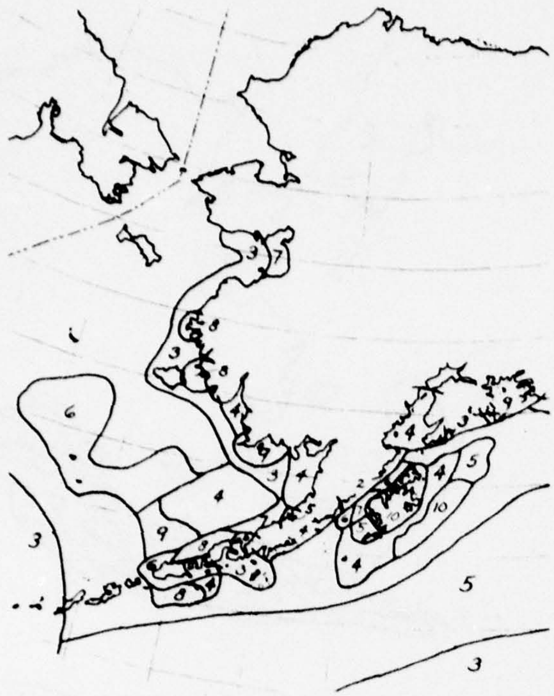


Figure 52. Ecological Sensitivity - May

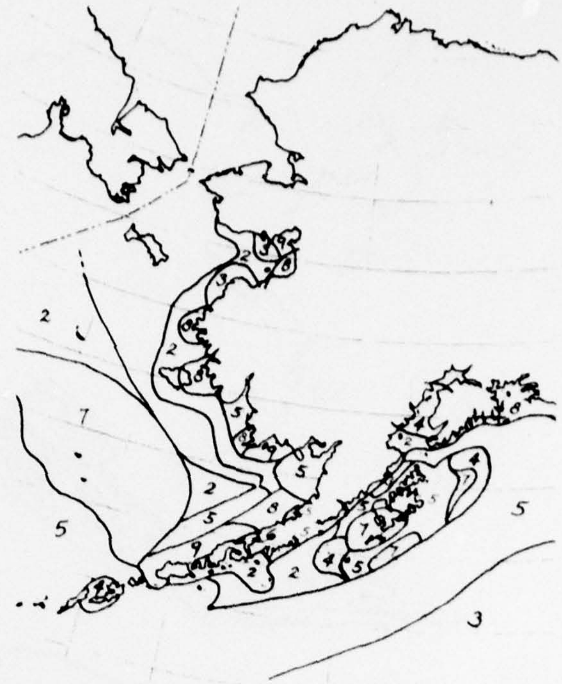


Figure 53. Ecological Sensitivity - June

Figure 54. Ecological Sensitivity - July

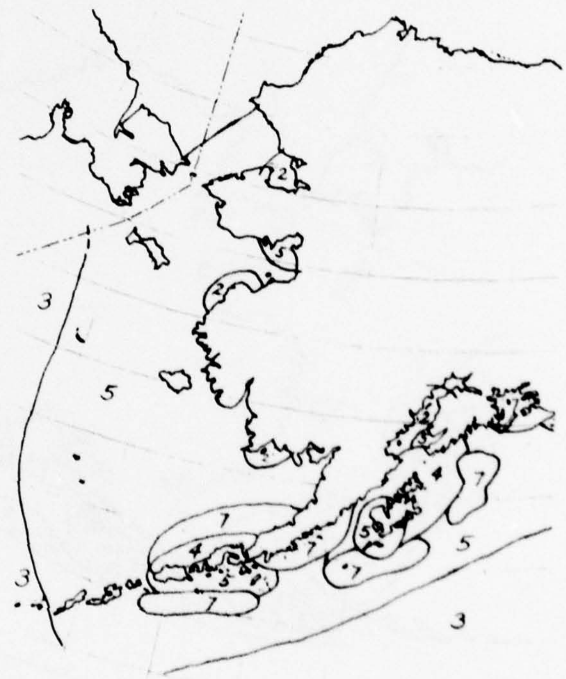


Figure 55. Ecological Sensitivity - August

Figure 56. Ecological Sensitivity - September

Figure 57. Ecological Sensitivity - October

Figure 58. Ecological Sensitivity - November

Figure 59. Ecological Sensitivity - December

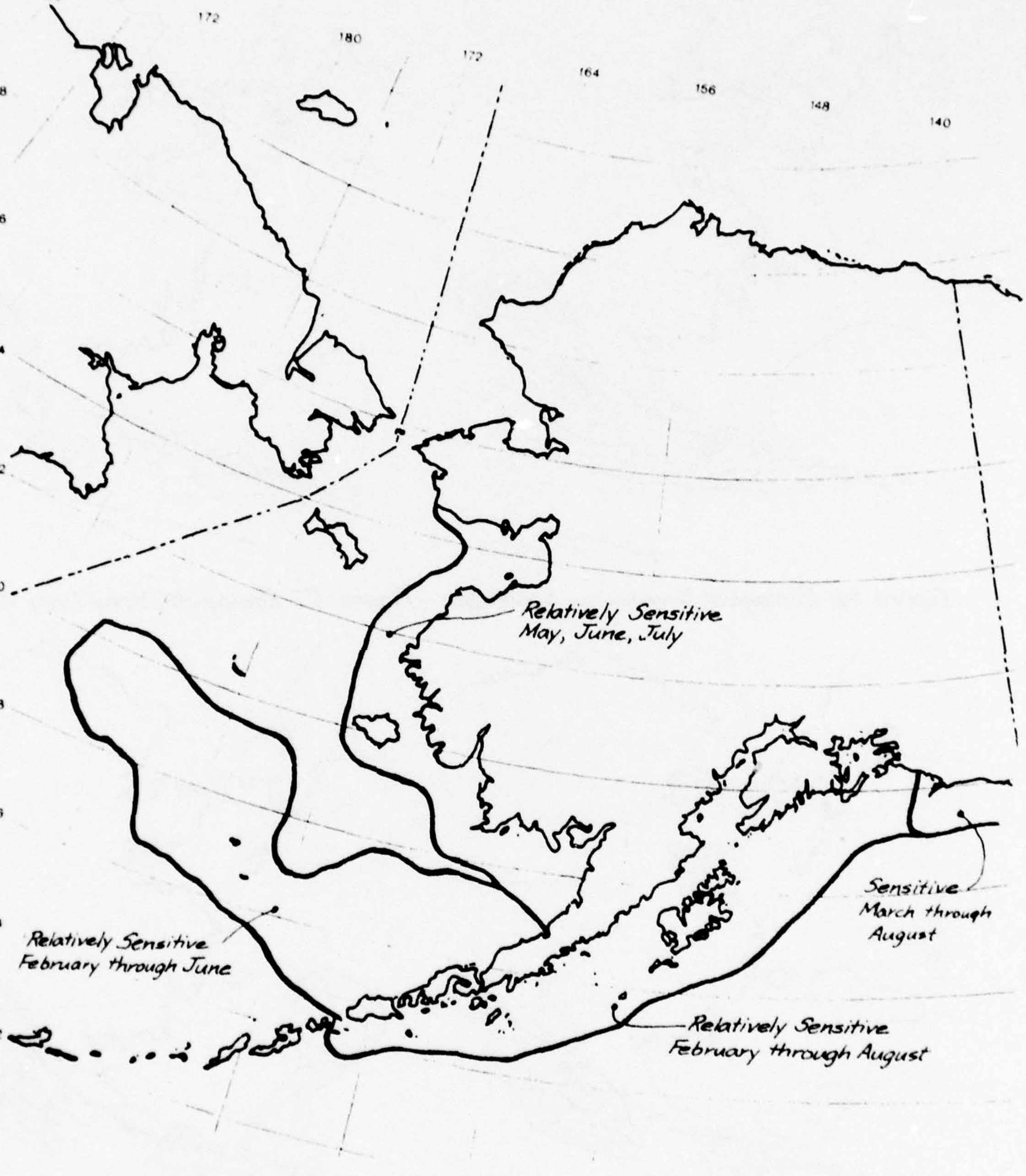


Figure 60. Overview of More Severe Relative Ecological Sensitivity of Alaskan Offshore and Coastal Regions Where Relatively Sensitive Areas are Those Rated at Level Six and Above

Spill Scenario Selection

Recalling that the objective of this portion of the program is to select oil spill scenarios which encompass the majority of spill and environmental conditions likely to be encountered in coastal and offshore Alaska, this section of the report describes the process by which the preceding information was used in the development of the recommended oil spill scenarios.

Table 16 is a summary of spill scenario considerations listed by geographic area for those geographic areas having petroleum potential. The information contained in this table is summarized from the preceding sections of this report. The first column identifies the geographic areas having petroleum development potential as previously summarized in Figure 3. The second column identifies the government/industry ranking of these potential petroleum reserves as adapted from Tables 5 and 6. This combined government/industry ranking is established on the basis of primary control by the government lease sale schedules and secondary control by expressed industry interest. The combined ranking is therefore established as the lease sale ranking for those areas for which lease sales have been scheduled, after which the industry preference ranking controls. The fourth column of Table 16 summarizes the ecological sensitivity of each area in accordance with the broad overview of ecological sensitivity summarized in Figure 60. The notable environmental conditions are summarized in the next column as adapted from Figure 47. The final column identifies the applicable spill type appropriate to each geographic area within the time frame of the present time to 1990. Two factors are incorporated in this determination, the timing of petroleum development as identified in Figure 5, and the location of crude oil transportation routes as identified in Figure 6.

Since it is desired to select representative scenarios covering the range of environmental conditions and the range of spill situations, one way to narrow the selection of geographic areas is to group geographic areas by common significant environmental conditions. Table 17 is such a grouping which reveals, at first glance, seven groupings of environmental conditions. Upon further investigation, however, it is apparent that the notable environmental conditions of Cook Inlet are similar to those of the Zhemchug Basin and Bristol Bay classification, where the latter two areas have the additional complication of earthquakes. Further refining the list of scenario locations, it is then possible to select one of the geographic areas out of each grouping by significant environmental conditions for further consideration. This selection is identified in Table 17 by italicizing the preferred geographic area. For the first set of notable environmental conditions, the Beaufort Sea was selected since it will likely be developed considerably in advance of the Chukchi Sea field. For the second grouping of environmental conditions, the Chukchi Sea was selected over Kotzebue Sound because of the top ranking of the Chukchi Sea in oil potential. For the third environmental condition grouping, Norton Sound was selected over St. Matthew Basin and the Navarin Basin because of its higher government/industry ranking, its greater oil potential, and the greater ecological sensitivity of the area. In the fourth environmental condition grouping, Bristol Bay was selected over the Zhemchug Basin due to the fact that the Zhemchug Basin was not ranked by industry, and the fact that the selection of Bristol Bay also covers Cook Inlet environmental

TABLE.16. SUMMARY OF SPILL SCENARIO CONSIDERATIONS FOR GEOGRAPHIC AREAS HAVING PETROLEUM POTENTIAL

Geographic Area	G/I Ranking	Oil Potential Ranking	Ecological Sensitivity	Notable Environmental Conditions	Applicable Spill Type to 1990
Beaufort Sea	2	2	Low	Ice, temperatures, light, visibility	Blowout, pipeline, tanker, barge
Chukchi Sea	8	1	Low	Ice, temperatures, light, visibility	Blowout, pipeline, tanker, barge
Kotzebue Sound	7	10	Low	Ice, temperatures, light	Blowout, barge, tanker
Norton Sound	5	7	Sensitive May, June, July	Ice, temperatures	Blowout, pipeline, tanker, barge
St. Matthew Basin	-	12	Low	Ice, temperatures	Barge, tanker
Navarin Basin	7	8	Low	Ice, temperatures	Blowout, barge
Zhemchug Basin	-	3	Sensitive February to June	Ice, temperatures, tides, earthquakes, snow	Blowout, pipeline, tanker, barge
St. George Basin	7	3	Sensitive February to June	Tides, earthquakes, storms, snow	Blowout, pipeline, tanker, barge
Bristol Bay	6	6	Sensitive February to June	Tides, earthquakes, storms, snow	Blowout, pipeline, tanker, barge
Aleutian Shelf	9	11	Sensitive February to August	Tides, earthquakes, storms, snow	Blowout, barge, tanker
Kodiak Shelf	4	9	Sensitive February to August	Waves, storms	Blowout, pipeline, tanker, barge
Cook Inlet	1	4	Sensitive February to August	Ice, temperatures, tides, snow	Blowout, pipeline, tanker, barge
Gulf of Alaska	3	5	Sensitive March to August	Waves, storms	Blowout, pipeline, tanker, barge

TABLE 17. GROUPING OF GEOGRAPHIC AREAS BY NOTABLE ENVIRONMENTAL CONDITIONS

Notable Environmental Conditions	Geographic Area
Ice, Temperatures, Light, Visibility	*Beaufort Sea*, Chukchi Sea
Ice, Temperatures, Light	*Chukchi Sea*, Kotzebue Sound
Ice, Temperatures	*Norton Sound*, St. Matthew Basin, Navarin Basin
Ice, Temperatures, Tides, Earthquakes, Snow	Zhemchug Basin, *Bristol Bay*
Tides, Earthquakes, Storms, Snow	St. George Basin, Bristol Bay, *Aleutian Shelf*
Ice, Temperatures, Tides, Snow	Cook Inlet
Waves, Storms	Kodiak Shelf, *Gulf of Alaska*

conditions. In the next grouping of environmental conditions, the Aleutian Shelf was selected primarily on the basis of its inclusion of Unimak Pass, which is the primary marine transportation route to the western and northern coasts of Alaska. In the final group of environmental conditions, the Gulf of Alaska was selected over the Kodiak Shelf because of its higher ranking by government and industry, and its greater oil development potential.

With the selection of these geographic areas as representing the range of environmental conditions likely to be encountered in coastal and offshore Alaska, it now remains to combine oil spill situations with these geographic locations in a logical manner. As previously indicated, six oil spill situations have been identified including a very large oil well blowout, an average size oil well blowout, a crude oil gathering pipeline rupture, a crude oil tanker casualty, a release of bunker C oil due to a crude oil tanker casualty, and the release of diesel oil due to a casualty involving a supply vessel or fuel oil barge. In placing these spill situations with the previously identified geographic areas, one obvious choice is to combine the very large blowout with the geographic area having the greatest oil potential. This then identifies one oil spill scenario as a very large oil well blowout in the Chukchi Sea. Considering the transportation routes shown in Figure 6, the Unimak Pass area of the Aleutian Shelf becomes an obvious choice for a transportation related spill situation. Based on industry's prior operating experience, and their future plans, it was determined that the transportation of diesel fuel by barge through the Bering Sea and Chukchi Sea will occur only in open water conditions. The spill situation consisting of the release of diesel fuel from a supply vessel or barge therefore is an open water spill situation, and is reasonably placed geographically at Unimak Pass. It should also be pointed out that the next most reasonable location for a diesel oil spill over the long term is judged to be in the Chukchi Sea area due to the grounding of fuel oil barges caused by heavy winds. Even in this situation, however, the casualty is associated with wind induced grounding rather than ice interaction, since the pack ice will be well offshore before transit to the Chukchi Sea is attempted. The supply barge casualty release of diesel fuel is therefore located in open water conditions at Unimak Pass.

The other transportation related spill situations consist of the release of either crude oil or bunker C fuel oil from a tanker. Referring back to Figure 6, the use of the three northern transportation routes through the Bering Sea will be based upon ice conditions, with the selected route moving westerly as ice conditions become more severe and proceeding back easterly as ice conditions diminish. With the likelihood that there will be crude oil transportation westward of St. Lawrence Island in the area of the Navarin Basin, and recognizing the great distance of such a spill situation from shore bases, a spill scenario based upon a tanker casualty in the Navarin Basin area is selected. A tanker casualty is also a realistic selection within the time frame of the study for Norton Sound since this region is projected for production by 1988 (Figure 5), and product transportation will likely be by tanker rather than pipeline. The crude oil release of 50,000 barrels previously selected compares to a potential Bunker C release of 7,000 barrels. Based upon the location of fuel tanks and cargo tanks, and the much greater volume associated

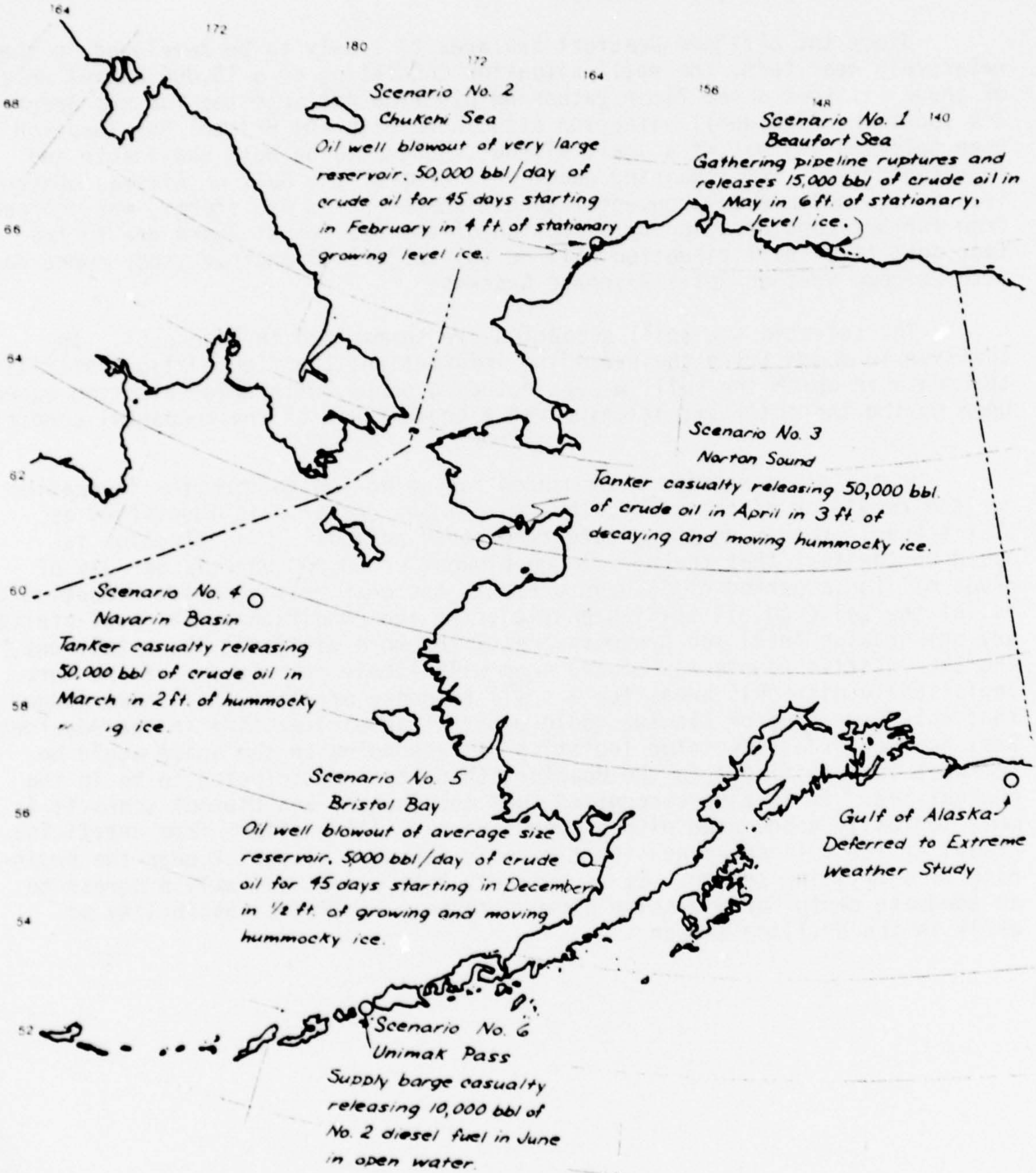


Figure 61. Summary of Selected Oil Spill Scenarios

with the crude oil spill, the bunker C spill was judged to be a less important case and the spill associated with the tanker casualties was selected as the crude oil spill of 50,000 barrels.

Since the offshore Beaufort Sea area is likely to be developed in the relatively near term, the spill situation consisting of a 15,000 barrel release of crude oil from a sea floor gathering pipeline was selected for the Beaufort Sea location. The spill situation associated with the Bristol Bay location was then selected as that of a small blowout, judged to be both reasonable and representative. The remaining geographic area of the Gulf of Alaska, characterized by its notable environmental conditions of waves and storms, was dropped from further consideration by direction of the U.S. Coast Guard due to the fact that this spill situation will be the subject of another study concerned with Extreme Weather Spill Response Systems.

The selected six spill scenarios are summarized in Figure 61. In addition to summarizing the preceding information, the figure also identifies the month in which the spill was selected to occur, with this selection based upon having the spill situations cover a broad range of environmental conditions.

Of the six scenarios recommended for selection to form the foundation for the remainder of the study, the Chukchi Sea scenario is identified as that scenario requiring the greatest response action. This selection is based on the fact that the very large blowout of 50,000 barrels per day of crude oil for a period of 45 days presents the most massive spill situation of all of the selected oil spill scenarios, the ice conditions of 4 ft of stationary but growing level ice presents one of the more difficult ice situations, and the relative remoteness of the area will likely make it one of the more logistically difficult areas for a spill response effort. It is also judged that this same type of blowout could occur at an earlier time in the Beaufort Sea, however, the associated logistics of responding to the spill would be somewhat less difficult in the Beaufort than it is anticipated to be in the Chukchi Sea. It is also recognized that the Chukchi Sea blowout scenario is most logically associated with a second year drilling effort from artificial gravel or ice islands, since its timing in February places it near the beginning of a drilling season. It is unlikely that a new well will progress to an adequate depth for a massive blowout to be a realistic possibility so early in the drilling season.

DEVELOPMENT OF ARCTIC SPILL RESPONSE SCENARIOS

Introduction

Using the six representative coastal and offshore Alaskan oil spill scenarios selected to encompass the majority of spill and environmental conditions likely to be encountered in the region as described in the preceding section of the report, the program proceeded with the development of spill response scenarios for the six oil spill scenarios. Alternative spill responses were to be identified, and a preferred oil spill response scenario was to be selected for each of the six oil spill scenarios for three levels of response capability, initially identified as 25, 50 and 90% response. The oil spill response scenarios were to include all functional areas of response including detection, surveillance, containment, recovery, temporary storage, transfer, disposal, logistics, ancillary, and emergency evacuation.

The problem of oil spill sensing may be thought of in two distinct parts. The first part is the problem of detection whereby a yes/no response to the presence of oil is obtained. A positive signal from an oil spill detection sensor therefore serves to initiate the oil spill response effort. The second part of the problem is that of oil spill surveillance where the location and areal extent of an oil spill is defined.

The surveillance subsystem of an oil spill response system must be capable of monitoring the movement of the oil spill and the progress of the oil spill response effort. The three parameters which are most important to the surveillance effort are the areal extent of the oil, regions of high oil concentration, and the drift of the spilled oil. This information is required by the command and control function to direct the oil spill response effort in an effective and efficient manner. Knowledge of the areal extent and drift of the spilled oil is required for the efficient placing of containment devices and the implementation of protective measures. The identification of regions of high oil concentration assists in the effective placing of oil spill recovery equipment.

In general terms, the initial actions to be taken in response to an oil spill are to first stop the release of oil from its source, and second, to limit the spread of the oil through the use of containment devices. The use of containment booms to restrict the area covered by an oil spill also serves to gather the oil into a thicker layer which generally results in more effective oil spill recovery operations. The containment function can also be thought of as a means for the immediate temporary storage of spilled oil.

The recovery function is concerned with the removal of spilled oil from the environment. The definition of the recovery function in terms of the removal of spilled oil results in some overlap of the recovery and disposal function, however this treatment has been established as common terminology in the field. The recovery function therefore includes a strict definition of recovery in terms of the physical removal of spilled oil, such as through

the use of a mechanical recovery device, after which there is an independent disposal function associated with the final disposal of the spilled oil. There are also other techniques used which are commonly called recovery techniques which inherently include both the removal of the spilled oil and the disposal of the spilled oil. Such techniques include, for example, in situ burning where the oil is removed from the surface and disposed of in the same process. Common terminology has resulted in the disposal function being primarily concerned with the disposal of oil which has been physically recovered, rather than including processes which result in the removal and disposal of oil in a single step.

Some form of temporary storage is generally required in most oil spill response efforts, usually as a buffer between the continuous oil recovery operation and the discontinuous oil disposal operation. The temporary storage function has also been separated into two stages, with the first stage denoted as immediate storage, providing for the temporary storage of recovered oil over a time period of three days or less, and temporary secure storage, which has been defined as the temporary storage associated with the time period greater than three days to as much as one year.

For cold regions aquatic spills of any significant size, three distinct transfer operations can be envisioned. The first transfer operation consists of transferring the recovered oil from the oil recovery device to the intermediate temporary storage system. The second transfer operation consists of transferring the oil from the intermediate storage system to a temporary storage system which would likely be land based. The third transfer operation would then consist of transferring the oil from this secure storage to the transportation system which takes the oil to its final disposal site. The transfer operation at the final disposal site will likely take place under temperate conditions rather than the more severe arctic conditions.

The disposal function is concerned with the disposition in an environmentally safe and acceptable manner of the oil and the associated contaminated material recovered from an oil spill.

The logistics function provides for the movement, maintenance, and disposition of equipment, supplies, facilities, communications networks, and services required for the support of the oil spill response effort. Because of the remoteness of the region, and the harsh environmental conditions for oil spill response operations, the logistics function becomes a major consideration in arctic oil spill response systems.

The major ancillary subsystems related to an arctic oil spill response system include weather forecasting, ice forecasting, spill behavior prediction, and the establishment of temporary navigational aids for support aircraft and vessels.

The final subsystem of the arctic oil spill response system is that for emergency evacuation. This subsystem provides for the immediate evacuation of personnel from hazardous ice conditions and provides access to medical facilities.

The work of establishing alternative oil spill response scenarios began with the gathering and review of all information on existing and planned oil spill abatement techniques and equipment for application in the selected oil spill scenarios. This information is summarized in Appendix B. In addition to reviewing all current information on existing and planned oil spill abatement techniques and equipment, an inventory of Alaskan onscene oil spill abatement equipment was developed with the assistance of Crowley Environmental Services Corporation, Anchorage. This inventory of onscene Alaskan oil spill abatement equipment is summarized in Appendix C. With this knowledge of existing and planned oil spill response capability, alternative oil spill response scenarios were developed for each of the six spill scenarios for three levels of response capability. While the initial levels of response capability were identified as 25, 50 and 90% response, it was revealed during the course of the study that for five of the oil spill scenarios the maximum possible oil spill response capability is 80%, and for the sixth case, the maximum oil spill response capability was determined to be at the 25% response level. These maximum response levels, which result from projections of the behavior of the spilled oil based upon the information given on the general behavior of arctic oil spills in Appendix D,will be more fully discussed in the following sections of this report.

The alternative spill response scenarios were developed with the emphasis placed upon the development of technically feasible, operationally practical, and environmentally acceptable approaches. In addition, the time frame of the study, with the early 1990's used as the upper planning limit for the study, and the stated objective of having a complete arctic pollution response system developed by the early 1980's, were major considerations.

In the sections that follow each oil spill scenario is addressed in terms of the oil spill mode, a description of the environmental conditions under which the spill occurs and spill response efforts must take place, a projection of the behavior of the spilled oil based upon the current state of knowledge of oil spill behavior in ice infested waters and the ice conditions present at the time of the spill,and the detailed description of the alternative and preferred spill response scenarios. With the development of the preferred arctic spill response scenarios for each of the six oil spill scenarios in this section of the report, the following sections are concerned with the cost of spill response and the effectiveness of spill response for the arctic spill scenarios.

Scenario 1 - Beaufort Sea

Spill Mode

The Beaufort Sea oil spill scenario consists of a rupture of an offshore subsea gathering pipeline resulting in the release of 15,000 barrels of crude oil in the month of May beneath stationary 6 ft thick level ice. This subsea gathering pipeline would be part of a production system and would

be located in a water depth of about 12 ft within the Barrier Island system since all offshore development in the Beaufort Sea within the time frame of this study is expected to occur within the Barrier Island system. The release of the 15,000 barrels of crude oil is assumed to be instantaneous.

Environmental Conditions

The condition of the ice cover between the northern coastline of Alaska and the Barrier Islands of the Beaufort Sea in the month of May is typically 6 ft of stationary level ice. Some small pressure ridges and ice rubble fields will be scattered throughout the area, but for the most part, because of the protection of the ice field by the Barrier Island system, the ice should be relatively uniform in thickness. The ice will begin to deteriorate in the month of June with the thickness declining through the month from 6 ft to 4 ft. In July the ice continues to deteriorate to a thickness of about 3 ft, and the stable ice deteriorates to form discrete ice floes. Little ice movement is expected because of the containment of the Barrier Island system until final breakup of the ice occurs in late July and early August. In areas close to major river systems which empty into the Beaufort Sea substantial flooding of the level ice sheet can be expected during periods of ice breakup.

The mean air temperature in the month of May is 19°F, increasing to above freezing at 34°F in June, and continuing to increase to 39°F in July. July is the warmest month of the year for this location. The water temperature is expected to remain relatively constant at about 28°F due to the near proximity of ice.

Water depths within the Barrier Islands of the Beaufort Sea are typically in the 2 to 7 fathom range, with the area under consideration having the more shallow depth of 2 fathoms. Currents in this region during the month of May are weak and primarily in the easterly direction at less than 0.1 knot. As ice breakup progresses, more open water becomes available and local surface currents may be generated by winds. Tidal excursions in the area are expected to be less than 1 ft.

Light conditions in the area are favorable during the month of May with continuous sunlight extending for 19 hours per day in early May. The area experiences 24 hour per day sunlight from the end of May through the end of July. During the month of May the area has a 17.4% frequency of visibility obstructions due to the fog and 4% due to blowing snow resulting in a 21% frequency of obstructions to vision, defined as a reduction in visibility to 6 miles or less. Eight days of heavy fog would be expected in May which would reduce visibility to 1/4 mile or less. Projecting forward to the months of June and July, the percentage frequency of visibility obstructions due to fog is expected to be near 26% in both months, while that due to blowing snow is negligible in June and in July. Heavy fog would be expected to occur on 12 days in June and 13 days in July.

Snowfall in the region averages 2 inches during the month of May. There is a 55% probability that this area will have 7 to 12 inches of snow on the ground in May and a 30% probability of there being 13 to 24 inches of snow on the ground. During the month of June the expectation for snow on the ground decreases to a 30% chance that there would be 1 to 3 inches of snow on the ground and a 51% chance that there would be only traces of snow on the ground. No snowfall would be expected in June or July. In July the warming trend continues with the probability that only traces of snow will be found on the ground increasing to 94%.

Mean wind velocities during the months of May, June and July are about 11.5 mph from the east-northeast in May, changing to easterly in June and July. No significant waves are anticipated in the area since during the period when ice is still predominant the amount of open water available for wave generation is quite limited. Even as ice breakup continues, the limited fetch due to the adjacent ice cover will result in insignificant wave action. Storms are not expected to be a significant factor in the area since the storm history averages half a storm per month in April, and 1.3 storms per month in June. Earthquakes also are not expected to be a significant factor since no earthquake epicenters have been recorded in northern Alaska.

Spill Behavior

Before oil spill response scenarios can be developed, it is necessary to project to the best extent possible the behavior of the spilled oil upon its release from the gathering pipeline. This section of the report consists of a description of one possible progression of the spill that could occur due to the changing environmental conditions summarized in the preceding section. Upon rupture of the subsea gathering pipeline, the crude oil released would rise to the underside of the stationary ice sheet and begin spreading beneath the ice. The oil being released at a temperature of 160°F will melt a cavity in the ice directly above the pipeline rupture which has been estimated to have the capacity to contain 1,000 barrels of the released oil. From this point, the oil would continue to radiate outward to some equilibrium thickness governed primarily by the underside surface roughness of the ice. In a recently reported study of ice thickness profiling conducted near Prudhoe Bay in mean ice thicknesses of 6.3 ft, Kovacs [15] discussed the role underice roughness would play in limiting the possible areal coverage of an oil spill beneath ice. Based upon his estimates, and considering the relatively large pocket of oil directly above the ruptured pipeline, the 15,000 barrels of crude oil would spread to an area of 8.9×10^5 sf, having a spill radius of 530 ft. It is estimated that about 25% of the spilled oil will collect in small pockets in the ice sheet, each having a capacity of about 2 barrels. The projected bahavior of the released oil is shown schematically in Figure 62.

Ice growth is relatively insignificant in this region during the month of May. Based upon the studies of the vertical migration of oil in ice performed by Martin [16], the oil can be expected to be initially

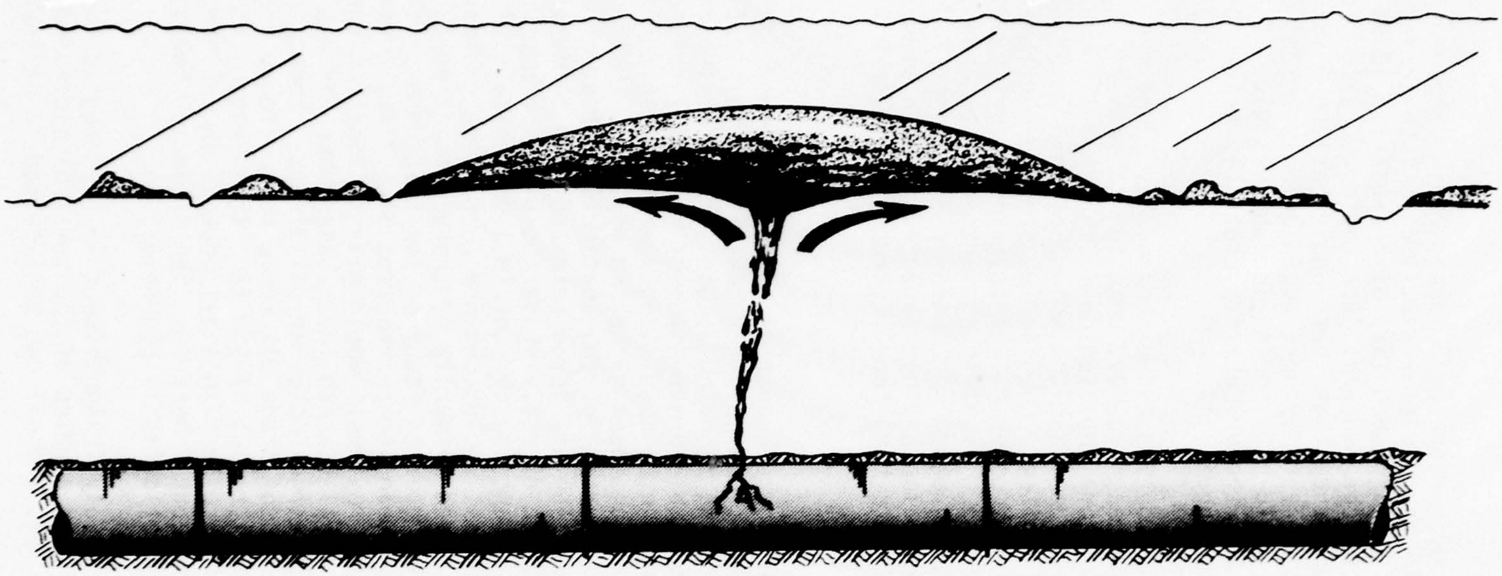


Figure 62. Schematic Depiction of the Release and Spreading of Oil in the Beaufort Sea Scenario.

absorbed into the ice to a depth of 2 inches, reaching a concentration of about 5% by volume. Little further penetration of oil into the ice would be anticipated for the following 45 days.

Several studies have indicated that oil located beneath ice ages at a much slower rate than oil exposed to the atmosphere. It is therefore assumed that the oil trapped beneath the ice would lose approximately 6% of its volume due to dissolution within a one week period of the spill.

When air temperatures rise above the freezing point in June, the ice will begin to deteriorate and brine channels will open in the ice cover which will allow oil to rise through the ice to the surface. The oil behavior is expected to be similar to that which was observed in the experimental spill at Balaena Bay where it was found that the rate of vertical migration of the oil increased with the level of solar radiation and the temperature of the air. By the end of June it is assumed that all of the oil spilled beneath the ice has been trapped within the ice or has reached the surface of the ice. Upon reaching the surface of the ice, the oil substantially reduces the solar albedo which causes an increase in the surface melting of the ice. Once melt holes develop and surface drainage patterns are established, the ice sheet will rapidly deteriorate. Based upon the Balaena Bay experiments, oiled areas are likely to be free of ice between 1 to 3 weeks earlier than the unoiled areas.

Oil beneath the ice which finds its way through the ice to pools on the surface will undergo increased weathering upon reaching the surface. It has been estimated that an additional 15% of the volume of the oil spilled will be lost through the weathering process in the month of June, making the total amount of oil available for cleanup approximately 12,000 barrels by the end of June. Because of the flooding of the ice from river floes near the end of May and in early June, there will be substantial puddling on the ice surface which will tend to further increase the areal coverage of the spilled oil. Near the end of June openings in the ice cover will result in still greater spreading of the spilled oil through crack systems in the ice cover. By the beginning of July little stable ice will remain and the area will consist primarily of ice floes. The free-floating oil will penetrate into these floes, resulting in an increase in the amount of oil contaminated ice. The typical penetration of oil into the ice will be to a depth of 2 inches, and up to a concentration of 5% oil by volume. As additional open water becomes available during the month of July, the oil will continue to spread to cover a much greater area, eventually spreading to an equilibrium thickness on open water of 0.73 cm. At this point, the 12,000 barrels of oil which remain after weathering losses will cover a spill area of 2.8×10^6 sf. The area of coverage could be further increased if currents, winds, and waves break the slick up into multiple small patches traveling in different directions. The area of contamination could also be increased through the distribution of the contaminated ice floes. As more oil is exposed to the atmosphere, weathering losses will continue up to 33% of the total volume of the oil spilled, resulting in the volume remaining available for cleanup declining to 10,000 barrels. The contaminated ice floes will leave a trail

of oil sheen in their wake as the ice continues to deteriorate and release the oil at a very slow rate.

This best estimate of the projected behavior of the oil spilled in the Beaufort Sea scenario based upon the preceding discussion is summarized in Figure 63. Presented in the figure are estimates of the areal coverage of the spilled oil, the volume of the oil entrained in the ice, and the volume of recoverable oil remaining as a function of time. The physical processes upon which these estimates are based are also identified in the figure. Variations in the areal coverage of the spill and the volume of spilled oil entrained in the ice are primarily functions of variations in ice conditions, while the variation in the volume of recoverable oil remaining reflects variations in the weathering of the oil as affected by variations in ice conditions. The plot of the volume of recoverable oil remaining shows, for example, that if no spill response effort was undertaken until August, the maximum possible spill response level would be 67%.

Spill Response

The spill will be detected by onscene operating personnel noticing a loss in operating pressure and flow through the gathering pipeline. The accident will be reported by these personnel to the proper authorities through normal channels of communication.

The surveillance function will initially consist of the task of defining the areal extent of the spill beneath the ice cover and the identification of areas of oil concentration. Conceptually, electrical surveillance devices such as impulse radars, microwave detectors and impulse laser fluorometers offer some degree of potential for detecting oil located beneath ice. However, none of these techniques have been demonstrated to date. A far less sophisticated alternative within the realm of current capability involves the use of truck mounted or sled mounted augers or drills. The extent of the oil spill could be determined by first locating the leak in the pipeline using divers, and then drilling holes through the ice along transects from the source of the oil until the circumference of the spill has been defined. Commercial drilling units which could be used in such an operation include the Nodwell drill which weighs 25,000 lbs and can drill a 4 inch hole through 6 ft of ice in approximately 5 minutes. Another commercially available drill is the Ingersoll-Rand T-5 Drillmaster which was used for drilling piling holes in the construction of the trans-Alaska pipeline. This drilling unit weighs 85,000 lbs and is capable of drilling a 24 inch diameter hole through 6 ft of ice in 4 minutes. Other alternatives requiring far greater labor content include the use of manual augers and ice saws. The identification of pockets of oil beneath the ice can be assisted by observation of the surface ice features such as hummocks, pressure ridges, and rafted ice, and observation of snow-covered areas which would likely identify regions of thinner ice cover because of the insulating effect of the snow cover. Another alternative surveillance technique consists of using divers beneath the ice cover to identify and mark the extent of the oil spill using some type of device which in all likelihood must be developed, or some technique which must be demonstrated. Diver access holes could be

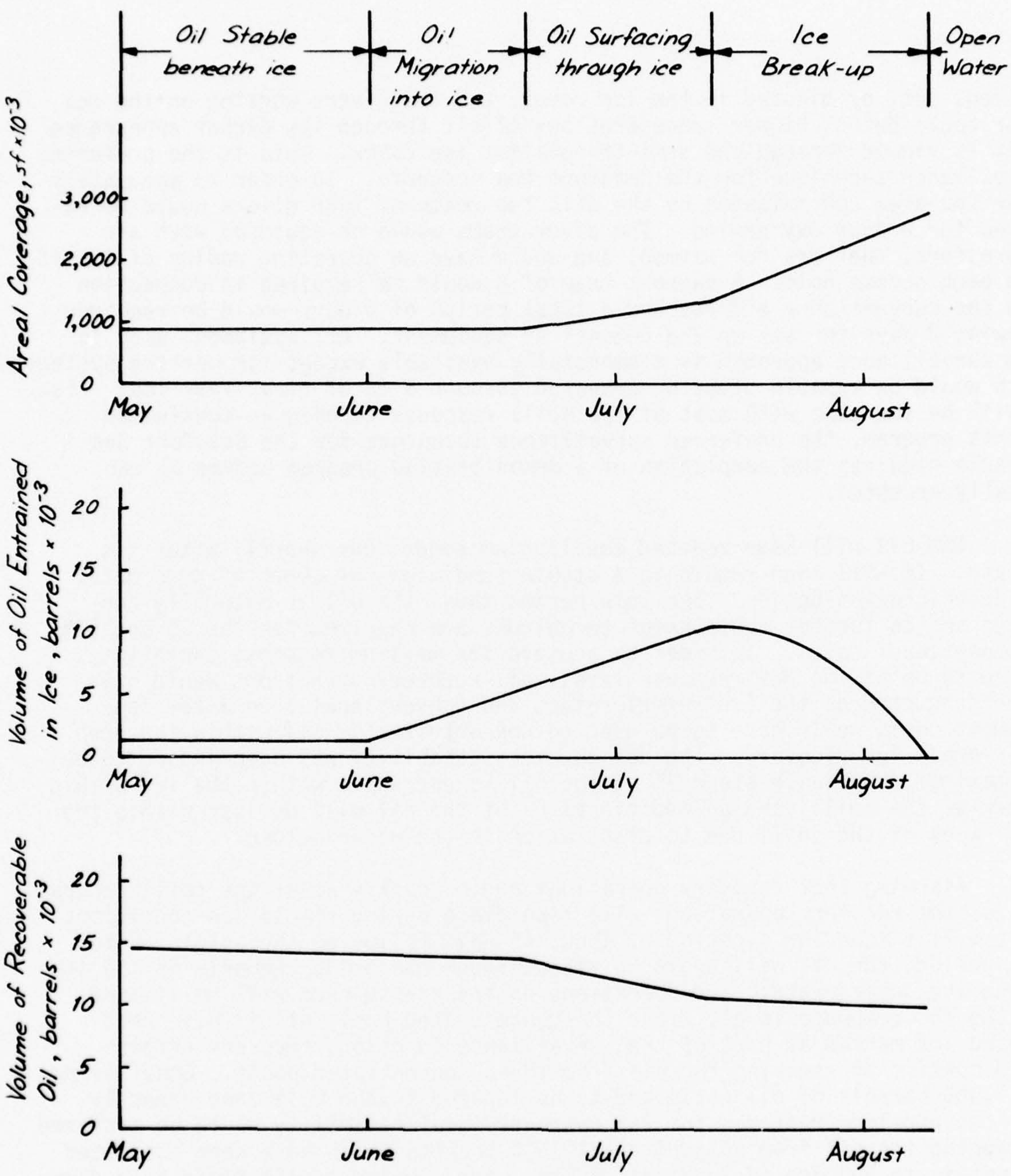


Figure 63. Summary of the Projected Behavior of Oil Spilled in the Beaufort Sea Scenario in Terms of Areal Coverage, Volume of Oil Entrained in the Ice, and the Volume of Recoverable Oil Remaining.

drilled, cut, or blasted in the ice cover, and the divers working on the sea floor could detect higher concentrations of oil through its darker appearance as it is viewed through the semi-transparent ice cover. This is the preferred surveillance technique for the Beaufort Sea scenario. In order to adequately cover the area contaminated by the oil, two teams of four divers would be required for a four day period. The diver teams would be equipped with air compressors, shelters for warmup, and would have an operating radius of 100 ft from each access hole. A support team of 8 would be required in connection with the surveillance effort, and a total period of 6 days would be required, allowing 2 days for set up and removal of equipment. All equipment used in this surveillance approach is commercially available except for marking systems which would be capable of being detected through 6 ft of first year ice. Also, as will be the case with most of the spill response techniques considered in this program, the preferred surveillance technique for the Beaufort Sea scenario requires the completion of a demonstration program before it can be fully accepted.

The oil will have reached equilibrium conditions shortly after its release. It will then remain in a stable condition for about 45 days until ice deterioration begins. For this period then, the oil is naturally contained and no further containment techniques are required for the 25 and 50% response level cases. In order to achieve the maximum response capability, judged to be at the 80% response level, oil recovery operations would have to be conducted as the ice deteriorates, and conventional open water containment booms would have to be used to concentrate the oil within the open water areas for recovery. The 80% recovery capability has been judged to be the maximum achievable since 9% of the oil is entrapped within the ice within 1 week of the spill, and an additional 6% of the oil will be lost within the first week of the spill due to dissolution in the water column.

Assuming that recovery operations begin shortly after the spill occurs, much of the recovery operation will take place during stable ice conditions which will extend for a period of about 45 days following the spill. After this period, the oil will begin to rise through the brine channels in the ice as the ice deteriorates, and operations on the ice surface will be limited. For the 25% response level, after the concentrated pools of oil have been located and marked as part of the surveillance function, recovery efforts would consist of removing the oil from these concentrated pools. Considering the 1,000 barrels of oil estimated to be located in the melt zone directly over the pipeline rupture, the 25% response level capability could be achieved by tapping the oil from an additional 1500 pockets which have been estimated to contain an average of 2 barrels of oil each. Using an oil field type downhole drill such as the T-5 Drillmaster, 24 inch diameter holes could be drilled through the 6 ft ice cover in about 4 min. Oil contained in the pockets beneath the ice cover would then flow into the hole. It has been estimated that in order to obtain the 25% response level, two teams of eight men, each equipped with a downhole drill with each team working 12 hour alternating shifts, would be required for a 9 day period. An additional period of 5 days

has been estimated to be required for setup and breakdown of this operation. Once the oil is accessible in the drilled holes, several alternatives are available for removal and disposal of the oil. The oil could be removed by direct suction using pumps capable of transferring high viscosity oil. Other innovative concepts such as conveyor belts, screw conveyors or agricultural type machinery could also be adapted to transfer the oil from the drilled holes to temporary storage containers. Another alternative is the use of an oil adherance material such as the Oil Snare manufactured by 3M. In order to achieve the 25% response level, it has been estimated that 840 cartons of 40 pads each would be required. A cherry picker could be used to dip the Oil Snare pads into the holes and transfer the oil soaked pads to dump trucks or other transfer vehicles. Another alternative, and the alternative which comprises the preferred response for the 25% response level, consists of burning the oil which surfaces in the drilled holes in situ. It has been estimated that by using an ignited oily rag to induce combustion in each of the holes, 90% of the oil in the holes could be removed and disposed of through in situ burning. It has also been estimated that there is enough pocket alleviation throughout the stable ice cover to provide access to over 25% of the oil in this manner. While this technique uses currently available equipment, the technique itself is conceptual and its suitability remains to be demonstrated.

In order to expand the response capability to 50%, means of gathering the oil which has spread to a lesser thickness beneath the ice cover rather than in concentrated pockets needs to be employed. The thickness of the oil in these regions is estimated to be less than 1 inch. The preferred technique for gathering the oil is to employ divers beneath the ice equipped with water hoses which would be used to direct the oil into the collection holes which had previously been drilled for the 25% response level case. It has been estimated that an additional 25% of the oil could be directed to the existing openings in the ice and made accessible for transfer or for the preferred disposal technique of in situ burning. The equipment required for use of this technique includes portable hydraulic pumps, air compressors, and warmup shelters for the divers. It has been estimated that two teams of four divers each would be required to work for about 22 days in order to cover the 890,000 sf area of spill coverage. An eight man team will be required for diver support, and five days were estimated to be required for set up and breakdown of this additional equipment. While it is judged that all equipment required for this operation is in existence, some development work is required in order to select the best equipment available with regard to both the pumping system and the type of nozzel to be used, since possible entrainment of oil within the water column is a concern.

Two techniques have been identified for further extending the response capability to the maximum achievable of 80%. One technique requires the physical removal and cleaning of the ice to gain access to the oil which has been absorbed into the bottom surface of the ice cover. Rock saws would be

used to cut 6 ft square blocks of ice which would be lifted by cranes out of the water, placed in some containment region, and cleaned of oil by spraying with steam. Once the ice blocks have been removed and cleaned, open water skimming techniques could be used to remove the remaining oil which would be floating on the surface of the open water. The equipment required would include two sets of rock saws, such as the R-100 Ditchwitch, a crane, bulldozers, boilers and steam spraying equipment. It has been estimated that fourteen crews of five men each, and seven sets of equipment would be required to obtain the desired level of response within the 45 day period of stable ice cover. An open water skimming device will also be required along with its two man operating team. An alternative approach which is far less manpower intensive has been identified as the preferred response. This is basically a continuation of the approach used to achieve the 25 and 50% response levels. After completion of the 50% response recovery operation, the ice would be perforated with an additional 1500 holes of 24 in. diameter with the objective of accelerating the melting of the ice cover in the contaminated area. The surrounding ice cover will remain stable and will serve as an effective containment system. After the contaminated ice has melted, open water skimming devices would be used in conjunction with conventional open water booms to concentrate the oil for recovery. This technique would require the use of two downhole drills for nine days of operation along with six days for setup and breakdown of the equipment. After the ice has melted, an eight man team working with two small boats, two open water skimmers, temporary storage bags, and a floating oil/water separator would recover the oil floating on open water. This approach is shown schematically in Figure 64. Also shown in the figure is a flaring burner mounted on a floating platform for disposal of the oil recovered in this manner.

Since in situ burning is the preferred technique for the 25 and 50% response levels there are no temporary storage requirements to be met for these cases. If in situ burning were not used and direct suction of the oil from the gathering holes were to be used for these cases, some type of temporary storage would be required. Possibilities include the use of the existing ice cover after a snow berm 3 to 4 ft in height had been formed and frozen over with water sprayed on the surface. Equipment required in order to construct snow berms of this nature would include front end loaders and bulldozers for constructing the snow berm, and pumps for spraying water on the snow berm. It has been estimated that two such temporary storage basins could be constructed within a two day period. Such a system would obviously only be applicable during the stable ice cover period. Conventional open top containers could also be used. For the 80% response level, the preferred technique does require a temporary storage system to store the oil that is being recovered by the open water recovery devices. Since the ice is in a deteriorating mode by the time this operation is complete and would be unsafe for land vehicles, the preferred technique is the use of air deployable, floatable, portable containment bags which would be used to store the oil for the brief period of time between recovery by the open water recovery device and disposal by the floating oil field burner.

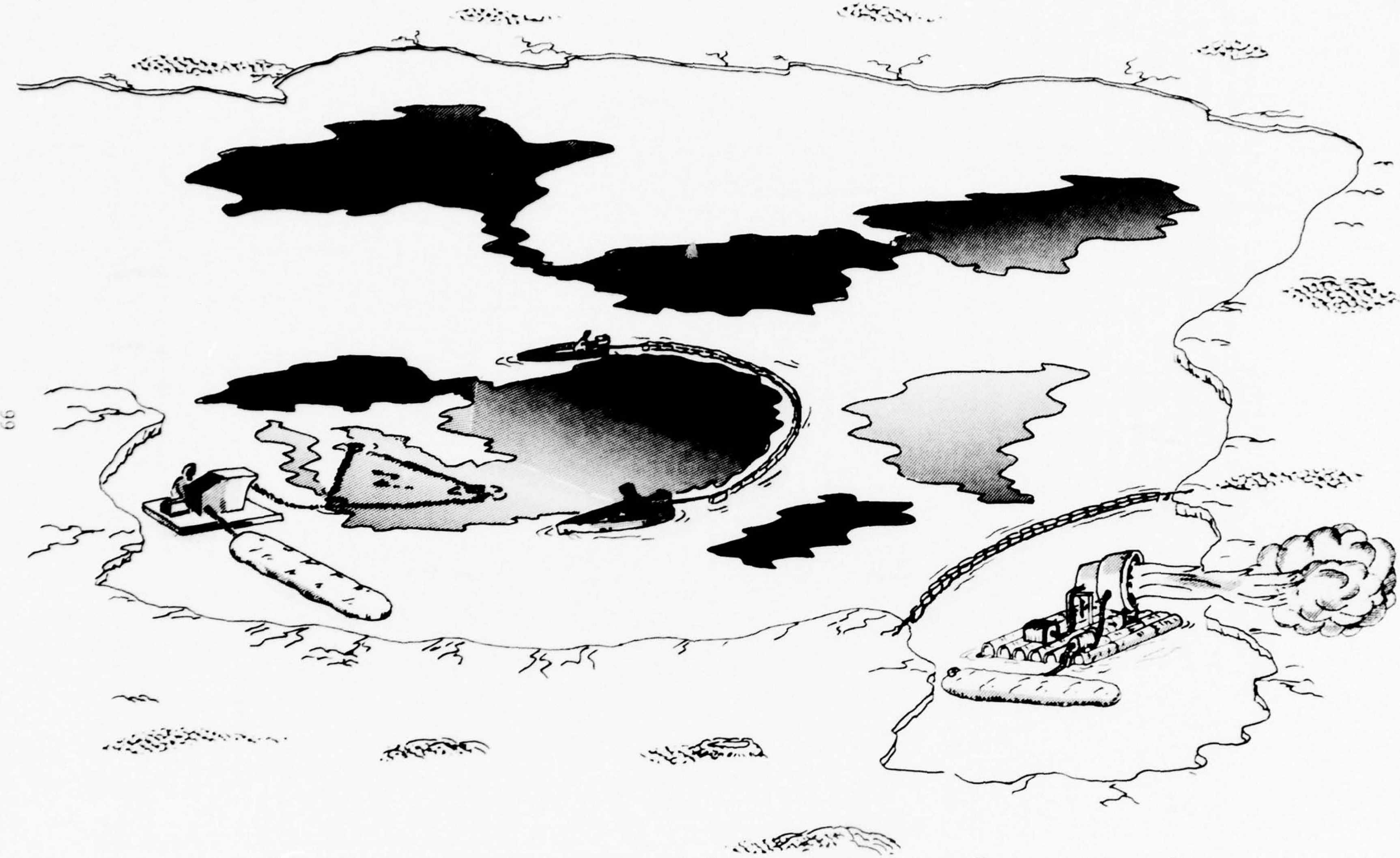


Figure 64. Schematic Representation of Conventional Open Water Recovery Methods Required to Achieve an 80% Response Level for the Beaufort Sea Spill

In a similar manner, the preferred response of in situ burning for the 25 and 50% response levels eliminates any need for transfer devices for these cases. If in situ burning were not used conventional pumps may not be adequate for transfer since there will be periods of time when the air temperature is below the -5°F pour point of the oil. The transfer techniques may then require some means for reducing the viscosity of the oil such as the application of heat or the use of a cutting stock. Neither of these options seems very practical, however, and it is judged that conventional pumping techniques would be abandoned in favor of unconventional transfer systems such as a screw conveyor or some type of bulk transfer equipment. The transfer function associated with the preferred 80% response level can be handled by conventional positive displacement or centrifugal pumps since air temperatures will be well above the pour point of the oil during this portion of the response operation.

As previously indicated, the preferred disposal technique for both the 25 and 50% response level is in situ burning. If this is not feasible, then other onscene means for disposal should be investigated such as open pit burning, or the use of open flame burners. Onscene disposal is the only practical disposal technique since the difficulty and cost associated with transferring the recovered oil to some distant disposal site makes this approach impractical. The disposal technique associated with achieving the 80% response level includes the use of an air transportable open flame burner for burning the oil recovered by the open water oil recovery device. In situ burning is not applicable for the 80% response level since the oil will be spread to a very thin layer on the open water. Other disposal technques which were considered and judged to be less desirable than the preferred techniques include the direct injection of the recovered oil back into the pipeline system over an extended period of time, and the disposal of the recovered oil in a disposal well if such exists nearby.

The logistics portion of the spill response scenario is based upon a spill location two miles offshore and 25 miles to the east of Slope Camp. Aircraft landing facilities at Prudhoe Bay are available for Hercules aircraft, therefore the logistics requirements consist of transportation from Kodiak or Anchorage to Prudhoe Bay and then on to Slope Camp. Ground transportation or helicopters could be used for the final transportation leg from Slope Camp to the spill site itself. An ice road would be prepared from Slope Camp to the spill site within a 2 day period using a grader and a front end loader. A small landing strip would be prepared near the spill site to facilitate emergency evacuation and for the transportation of personnel between the spill site and Slope Camp. During the final phase of the 80% response case, the ice would be unsafe for road vehicles and for landing fixed wing aircraft, while at the same time ice conditions would be too severe for open water shallow draft marine vessels. During this time period the primary transportation mode will therefore be helicopters. Due to the established onshore oil field operations at Prudhoe Bay, ice cutting equipment, storage tanks, trucks and miscellaneous heavy mechanical equipment will be available. The special cold weather clothing used by the oil spill response team must be oil resistant.

Ancillary spill response functions will be the same for all levels of spill response. Weather forecasts will be obtained hourly from available sources. The spill site will be marked with radio beacons to assure that helicopters can locate the site in the event of adverse weather conditions or if the need exists for emergency evacuation. Members of the spill response team would be equipped with individual emergency beacons. Immediate emergency medical facilities are available at Prudhoe Bay and emergency cases can be flown on to Fairbanks or Anchorage within a few hours. At least one light helicopter should be reserved at all times for use in emergency evacuation while spill response operations are underway.

The preferred response techniques for the three levels of spill response capability are summarized in Table 18 for the Beaufort Sea oil spill scenario. The labor and equipment associated with the preferred oil spill responses developed for this scenario are summarized in Tables 19, 20, and 21 for the 25, 50 and 80% response levels respectively.

TABLE 18. SUMMARY OF PREFERRED SPILL RESPONSE TECHNIQUES FOR THE BEAUFORT SEA SPILL SCENARIO

Function	25% Response Level	50% Response Level	80% Response Level
Detection	Monitor pressure and flow loss	Same	Same
Surveillance	Diver observation beneath the ice	Same	Same
Containment	Natural	Natural	Natural and open water booms
Recovery	Drill holes in ice to gain access to the oil; burn in situ	Same plus divers flush thinly spread oil to collection holes	Same plus accelerate ice deterioration and skim oil from open water
Storage	None	None	150 bbl floating bladders
Transfer	None	None	Conventional pump
Disposal	Burn in situ	Burn in situ	Burn in situ and with open flame burner
Logistics	Prudhoe Bay to Slope Camp to spill site; ice road, fixed wing aircraft, helicopters	Same	Same
Ancillary	Weather and ice forecasts, marking beacons, communications equipment	Same	Same
Emergency Evacuation	Dedicated helicopter, personnel emergency beacons	Same	Same

TABLE 19. EQUIPMENT AND LABOR ASSOCIATED WITH 25% RESPONSE TO SCENARIO NO. 1 - BEAUFORT SEA

A. SURVEILLANCE

1 Nodwell Drill (25,000 lb)
8 Divers
6 Support Staff for Divers
2 Equipment Operators
2 Air Compressors
1,500 Under-ice disposable markers
Power Pack

Logistics for Surveillance

Transport of Men & Equipment to Site
2 Warm Up Shelters (30 x 10 ft trailers)
1 Bulldozer (D-9 or similar)
1 Crew Transport Vehicle
2 7.5 kva Generators (500 lb each)
4 50,000 BTU Space Heaters
Miscellaneous
Consumables and Lodging at Base Camp

B. CONTAINMENT

None

C. RECOVERY (9 days for operation, 5 days setup & breakdown)

2 Supervisors
2 Foremen
4 Equipment Operators
3 Laborers
2 T-5 Downhole Drill Masters (85,000 lb each)
Diesel Fuel (1,700 gal in 50 gal drums)

Logistics for Recovery

Transport of T-5 Downhole Drill Masters
2 Warm Up Shelters
1 Crew Transport Vehicle
1 Support Helicopter
4 7.5 kva Generators
4 50,000 BTU Heaters
6 Sets of 1,000 watt Lights
Miscellaneous
Consumables and Lodging at Base Camp

TABLE 19. EQUIPMENT AND LABOR ASSOCIATED WITH 25% RESPONSE TO SCENARIO NO. 1 - BEAUFORT SEA (Continued)

D. STORAGE

None

E. TRANSFER

None

F. DISPOSAL

In Situ Burning

G. ANCILLARY

1 Radio Beacon, Aircraft Navigation Frequency
Communications Equipment

H. EMERGENCY EVACUATION

1 Support Helicopter
8 Individual Emergency Beacons

TABLE 20. EQUIPMENT AND LABOR ASSOCIATED WITH A 50% RESPONSE TO SCENARIO NO. 1 - BEAUFORT SEA

A. SURVEILLANCE

Same as 25% response

B. CONTAINMENT

None

C. RECOVERY (22 days for operation, 5 days setup and breakdown)

25% Response List
1 Manager
1 Foreman
2 Equipment Operators
4 Laborers
8 Divers
8 Support Staff for Divers
2 Air Compressors
3 Special Systems for Detecting Oil Under Ice
2 T-5 Downhole Drill Masters (85,000 lb each)
Diesel Fuel (1,700 gal in 50 gal drums)

Logistics for Recovery

3 Warm Up Shelters (30 x 10 ft trailers)
Transport of Downhole Drill
Crew Transport Vehicle
3 7.5 kva Generators
6 50,000 BTU Heaters
Miscellaneous
Consumables and Lodging at Base Camp

D. STORAGE

None

E. TRANSFER

None

F. DISPOSAL

In Situ Burning

G. ANCILLARY

1 Radio Beacon, Aircraft Navigation Frequency
Communications Equipment

TABLE 20. EQUIPMENT AND LABOR ASSOCIATED WITH A 50% RESPONSE TO SCENARIO NO. 1 - BEAUFORT SEA (Continued)

H. EMERGENCY EVACUATION

1 Support Helicopter
16 Individual Emergency Beacons

TABLE 21. EQUIPMENT AND LABOR ASSOCIATED WITH AN 80% RESPONSE TO SCENARIO NO. 1 - BEAUFORT SEA

A. SURVEILLANCE

Same as 25% response

B. CONTAINMENT

500' of Open Water Boom

C. RECOVERY (15 days for drilling holes, 2 days for breakdown)

25 and 50% Response List
4 Equipment Operators
2 T-5 Downhole Drill Masters (85,000 lb each)

Logistics for Recovery

1 Warm Up Shelter (30 x 10 ft trailer)
1 Crew Transport Vehicle
1 7.5 kva Generator (500 lb)
2 50,000 BTU Heaters
Miscellaneous
Consumables and Lodging at Base Camp

RECOVERY - AFTER ICE MELTS (9 days for recovery, 6 days setup and breakdown)

1 Supervisor
7 Equipment Operators
2 16 ft. Work Boats
2 Open Water Skimmer Heads
1 400 gpm Oil/Water Separator

Logistics for Recovery

2 Floating Platforms (small work boats)
Sky Crane
Miscellaneous
Consumables and Lodging
Logistics to Get Equipment to Site

D. STORAGE

5 600 gal Floating Portable Bladder Tanks (100 lb each)

E. TRANSFER

3 200 gpm at 150 ft Discharge Self Priming Portable Pumps

TABLE 21. EQUIPMENT AND LABOR ASSOCIATED WITH AN 80% RESPONSE TO SCENARIO NO. 1 - BEAUFORT SEA (Continued)

F. DISPOSAL

Open Flame Burner Systems for 125 bbl/hr (6,000 lb)

G. ANCILLARY

1 Radio Beacon, Aircraft Navigation Frequency
Communications Equipment

H. EMERGENCY EVACUATION

1 Support Helicopter
8 Individual Emergency Beacons

Scenario 2 - Chukchi Sea

Spill Mode

The oil well blowout of a very large reservoir in the Chukchi Sea is envisioned as a release from a ground fault within 100 ft of the drill rig representing a worst case blowout. The release of oil at the rate of 50,000 barrels per day will be accompanied by a release of gas at the rate of 750 scf per barrel of oil. Based upon the assumption that a 45 day time period is required for successfully arresting the blowout through the drilling of a relief well,the total volume of crude oil released will be 2,250,000 barrels. This oil spill scenario is based upon the assumption that the blowout is associated with exploratory drilling conducted on a seasonal basis from an artificial gravel island or an artificial ice island. The time placement of this spill in the month of February, at the beginning of a drilling season, makes it reasonable to place this spill situation in the second season of drilling when the drilling is resumed at significant depths. As was the case with the Beaufort Sea oil spill scenario, the Chukchi Sea spill scenario is based upon petroleum development occurring within the time frame of concern in this study in the area between the coast and the Barrier Islands. The ice conditions in the region are therefore assumed to be stable, with the ice contained in the area between the coast and the Barrier Islands.

Environmental Conditions

At the time of the blowout in early February, ice conditions in the region consist of 4 ft thick growing stationary ice. Ice growth continues through February and March with the ice thickness reaching 6 ft by the end of February, and 7 ft by the end of March. Ice growth then slows, with the ice thickness stabilizing at about 7 ft through the month of April. Because the oil spill scenario was based upon petroleum development occurring in the area between the coast and the Barrier Islands, the ice is assumed to be stationary.

The mean temperature in this area during the month of February is -19°F. February is the coldest month of the year, with minimum temperatures extending to as low as -55°F. Temperatures increase somewhat during the month of March to a mean value of -16°F, and continue rising in April to a mean of -1°F. Water temperatures throughout this period would be constant at 28°F.

Water depths within the Barrier Island system in the Chukchi Sea are less than 2 fathoms. Currents within the Barrier Island system are negligible during the winter, and any currents present would be expected to be in the northeasterly direction. The tidal range in this area will be less than 1 ft, and there will be two tides per day.

During the month of February, this area would experience five hours of continuous sunlight and nine hours of continuous sunlight and twilight. In March and April the period of sunlight increases to ten hours and sixteen hours respectively. Continuous sunlight will be present during the later

part of May. Obstructions to visibility would be expected during the month of February 13.1% of the time due to fog, 12.6% due to blowing snow, and 0.3% due to smoke or haze, resulting in a 25% occurence of obstruction to vision, defined as a condition where visibility is reduced to 6 miles or less. Two days in the month of February would be expected to have heavy fog, defined as a condition where the visibility is reduced to 1/4 mile or less. Obstructions to vision in March would be expected to occur 7.9% of the time due to fog, 10% of the time due to blowing snow and 0.2% due to smoke or haze, resulting in the expectation of obstruction to vision during March 18.3% of the time. Heavy fog would be expected for one day in the month of March. Visibility improves only slightly during Arpil with obstruction to vision expected 9.3% of the time due to fog, 7.8% due to blowing snow, and 0.2% due to smoke or haze resulting in an expectation of obstruction to vision 16.7% of the time. In the month of April, three days of heavy fog could be expected.

In the month of February there is a 50% chance that the snow cover on the ground will range from 13 to 24 inches, and a 48% chance that there will be 7 to 12 inches of snow on the ground. During the months of March and April, there is a 50% chance that there will be 7 to 12 inches of snow on the ground, and also a 50% chance that there will be 13 to 24 inches of snow on the ground.

Mean wind velocities in this area during the month of February are 10.9 mph from the east. Mean wind velocities increase to 11.2 mph in March from the east-northeast, and 11.5 mph in April from the northeast. The average number of storms in this area is only 0.1 per month for February, March and April. Waves will not be a consideration in the area during this time period due to the heavy ice cover. This area in the past has been relatively earthquake free, however it is still ranked as having a moderate probability for structural damage due to earthquake activities.

Spill Behavior

The oil well blowout from a ground fault within 100 ft of the drill rig results in the release of oil at a rate of 50,000 barrels per day accompanied by a release of gas at the rate of 750 scf per barrel of oil over a period of 45 days. The ice cover directly over the blowout will partially melt, and the remaining ice will fracture within the first day, after which most of the gas will be vented into the atmosphere. Oil will spread onto and beneath the stable ice cover. The oil spreading beneath the ice will spread radially, filling interconnecting ice pockets on the underside of the ice and becoming more heavily concentrated in deeper pockets formed by rafted ice, hummocks, and pressure ridges. The gas that is not vented will also spread beneath the ice and rise to the under ice surface thereby filling interconnecting pockets with gas and limiting the amount of oil which can be contained in the under ice pockets. If most of the gas is vented and the gas does not significantly affect the pocket filling process, the areal coverage of the spill will be about 65 sf per barrel, corresponding to a nominal oil thickness of slightly more than 1 inch. If the gas does play a major role in filling the under ice surface roughness, the areal coverage will be 240 sf per barrel of

oil, assuming an oil slick thickness of 0.28 inches. The response scenario is based on the assumption that most of the gas is vented through the broken ice cover directly over the blowout, and the gas therefore does not affect the containment of oil by the rough undersurface of the ice.

The oil, assumed to have a pour point of -5°F, which spreads onto the upper surface of the ice will solidify due to cooling to the mean air temperature of -19°F. As this occurs, it is conceivable that a rim of oil will build up on top of the ice surrounding the opening formed in the ice cover by the blowout which will further limit the spreading of oil on top of the ice. It is therefore assumed that only 5% of the oil will flow on top of the ice cover, with the remaining 95% being distributed beneath the ice cover.

One day after initiation of the blowout, the heat of the released oil will have melted a hole in the ice cover about 10 ft in diameter. By the time the blowout is arrested with the completion of a relief well after 45 days, the diameter of the melt hole will have increased to 375 ft. Assuming that the oil reaches an average thickness in this melt hole of about 5 ft, 5% of the total spill volume will be contained in this melt pool. Further natural containment will result from the relatively slower ice growth rate in the area affected by the oil spill. The ice thickness will be relatively thinner near the blowout, and relatively thicker farther away from the blowout. By the time the blowout is arrested it is estimated that the ice thickness will vary from 4 ft near the blowout to 5 ft at a distance of 400 ft from the blowout. Upon termination of the blowout, the spill radius is estimated to be 2,750 ft.

It is estimated that 6% of the oil will be lost due to aging, and 2% of the spilled oil will be entrained in the ice by the time the blowout is arrested. The low air temperatures through the months of March and April will result in an ice layer 18 inches thick growing beneath the oil. The oil will therefore be sandwiched within the ice. The oil will then remain stabilized until air temperatures increase to the point where brine channels begin to form in the ice which allow the oil to migrate vertically to the surface of the ice. The oil will therefore remain in a stable condition within the ice in a relatively unweathered state until ice decay begins in June.

The best estimates of projected oil spill behavior in the Chukchi Sea scenario are summarized in Figure 65 in terms of the areal coverage of the spill, the volume of oil entrained within the ice, and the volume of recoverable oil remaining available as a function of time. The determination of the volume of recoverable oil remaining is based upon the assumption that the oil spilled on top of the ice and the oil contained in the melt pool weathers to 15% of its volume after the first 45 days, and another 15% by the end of 3 months. The oil spilled beneath the ice cover is assumed to undergo a 6% loss due to dissolution in the water column by the end of the first 45 days.

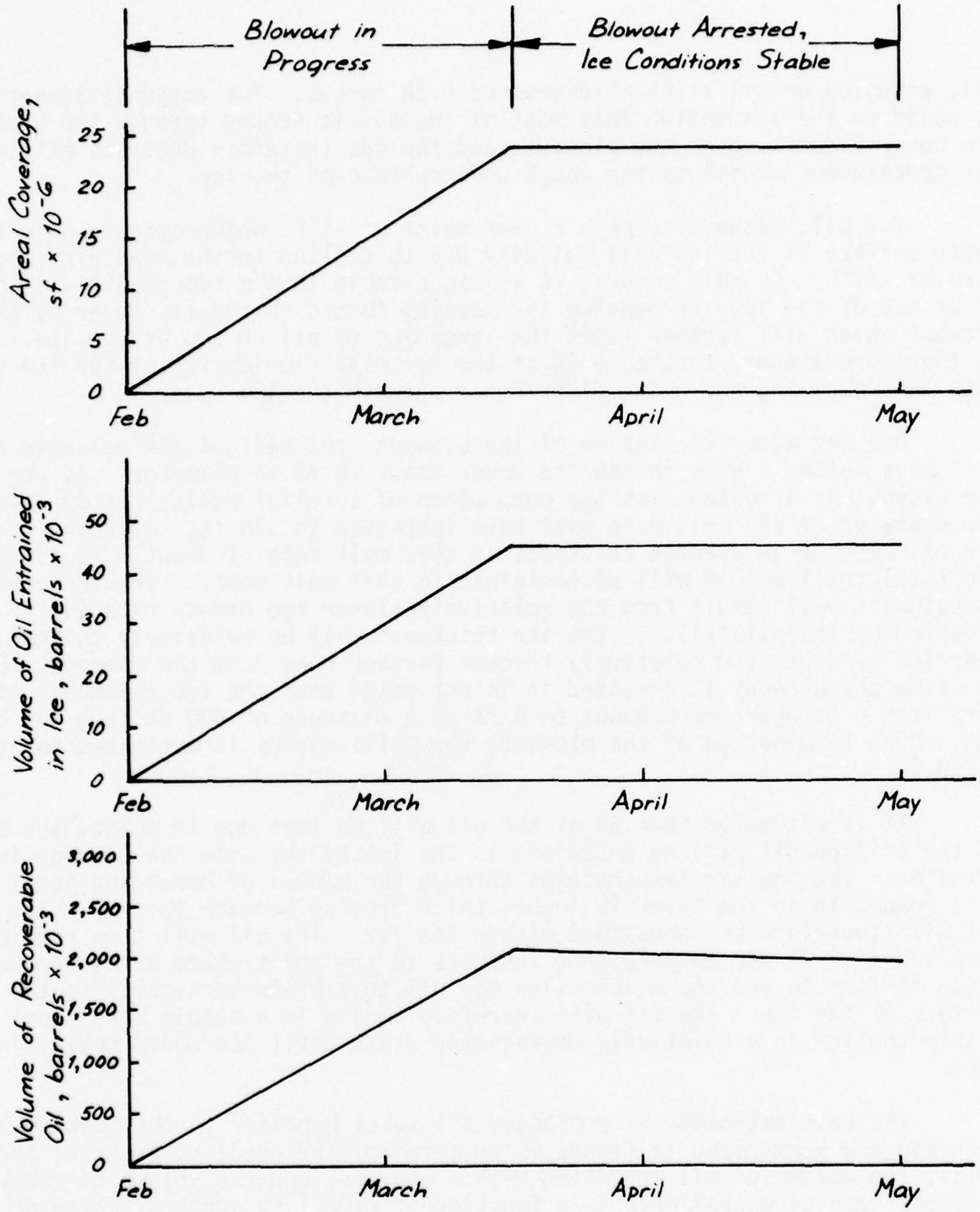


Figure 65. Summary of the Projected Behavior of Oil Spilled in the Chukchi Sea Scenario in Terms of Areal Coverage, Volume of Oil Entrained in Ice, and the Volume of Recoverable Oil Remaining.

Spill Response

It is assumed that the blowout will be detected by operating personnel on the drill rig. The incident will be reported to the base camp on the Chukchi coast, and then relayed through normal communications channels to the appropriate authorities.

In the Chukchi Sea oil spill scenario, the surveillance function is concerned with oil spilled on top of and beneath ice. It has been estimated that 5% of the oil spilled will be located on top of the ice cover, and that this oil will layer to a significant thickness as a result of the -5°F pour point of the oil and the mean air temperatures in February of -19°F. Snow cover may obscure a portion of the surface oil requiring the use of a technique which could detect oil beneath snow cover. While some devices such as a pulsed laser fluorometer, a gas sniffer, and a microwave detector show some promise for detecting snow covered oil, their capabilities have not been demonstrated to date. The preferred technique for defining the limits of the oil spilled on the surface will therefore be to disturb any snow cover and probe for the presence of oil through visual observation from some ice supported vehicle. The problem of detecting oil located beneath the ice is further complicated over the long term by the likelihood that the oil will be sandwiched within ice in the form of an oil lense. Again, while microwave detectors and pulsed laser fluorometers may have some application, their usefulness has not been demonstrated to date and they therefore cannot be identified as the preferred surveillance technique. It may be possible to use divers operating beneath the ice cover for locating concentrated pools of oil and outlining the areal extent of the spill as was done in the Beaufort Sea scenario, however the limited period of sunlight at the time of the Chukchi Sea spill, and the likelihood of snow cover during February, would make it far more difficult to locate the presence of oil beneath ice by distinguishing color variations due to light passing through the stable ice cover. If such a surveillance operation were delayed until more favorable light conditions existed, the ice growth beneath the oil would be approximately one additional foot, which also would inhibit the detection of oil filled pockets by divers operating beneath the ice cover. The preferred surveillance technique for the Chukchi Sea scenario is therefore to probe for the presence or absence of oil by making transects from the source with ice drills. Drills similar to those described in the Beaufort Sea scenario could be used in a similar manner to identify areas of oil concentration and the limits of the areal extent of the spill. The areas of high oil concentration could be anticipated to some extent by observing the upper surface features of the ice such as pressure ridges, rafted ice, rubble fields, and compacted snow. The boundaries of the spill would then be outlined with markers, and concentrated pools of oil would be marked for subsequent recovery operations. As will be evident from the following discussion, the use of this surveillance technique is required only for the 80% response level case.

Several techniques are worthy of consideration for use in containing oil spilled beneath ice. One technique developed by Panarctic Oils, Limited is to slot the ice and insert a containment boom, which extends below the ice

cover into the slot, and allowing it to freeze in place. The Panarctic approach uses a boom with a 12 ft skirt, which in 6 ft of ice would result in an additional 6 ft depth of containment capability. Another possibility for containment is to surround the blowout with a manmade ice keel. Water could be pumped on the ice surface, which upon freezing, would result in deformation of the ice sheet below the builtup area and the formation of an ice keel. Another possible concept is to use trenching devices to cut slots in the ice in which the oil would rise and concentrate; however, the great volume of oil being released in this blowout combined with the likelihood of the re-freezing of any slots in the ice cover due to the extremely low temperatures makes this approach unrealistic. A containment pocket could also be formed in the ice sheet by insulating a portion of the ice cover in the vicinity of the blowout with insulation mats or snow cover while the ice is still in the growing mode so as to cause the ice in that region to grow at a slower rate than the surrounding uninsulated ice. The preferred containment response, however, is to undertake no action associated with the containment function. The melt hole developed in the ice over the blowout, and the natural underice roughness, will result in a substantial amount of containment of the spilled oil. In addition, because of the simultaneous release of gas with the oil, it has been judged that it would be unsafe to conduct spill response operations any closer than 2,000 ft from the blowout. This 2,000 ft operating radius eliminates consideration of any of the previously discussed containment techniques since the radius of the spill with no additional containment action is only 2,700 ft due to the natural containment of the melt hole and the underice features.

The preferred recovery technique for the 25% response level consists of taking advantage of natural processes to gain access to the oil. Once access to the oil is gained, the preferred disposal technique is in situ burning, therefore no independent recovery function is associated with this response level. Based on the estimation that oil would be available at a thickness of 5 ft in the 375 ft diameter melt hole over the blowout, approximately 5% of the oil will be contained in this melt hole. It has also been estimated that an additional 5% of the oil will be located on the surface of the ice surrounding the melt hole. This oil will be in a semi-solid state, and could be physically pushed into the melt hole with the help of bulldozers and front end loaders, and subsequently disposed of through in situ burning. About 10% of the total volume of oil spilled could therefore be disposed of in this manner after the blowout has been arrested. The additional 15% required to achieve the desired 25% response level will begin to surface and form concentrated pools of oil on the ice in June as the ice deteriorates. The surrounding ice would still be in a stable condition, since the oil is located at the 4 ft ice depth and the surrounding ice is 6 ft in thickness. Crews working from the ice, or from helicopters, could ignite these concentrated oil pools and the oil would be disposed of through in situ burning.

In order to achieve higher levels of response capability, the preferred technique consists of initiating in situ burning while the blowout is still in progress. Based on the assumption that a relief well could be drilled about 4,000 ft away from the blowout itself, it would be possible to burn oil in situ

while the blowout is underway. This preferred response applies to both the 50 and 80% response levels. In the case of the 50% response level, if in situ burning cannot be initiated while the blowout is still in process, the most feasible alternative approach would be to wait until the spring thaw when brine channels in the ice open up and oil is allowed to migrate through the ice and form concentrated pools of oil on the ice surface. These concentrated pools could then be burned in the same manner as was employed for the 25% response level, and it is estimated that the 50% response level could be satisfactorily achieved through the use of this technique. Any alternatives not employing in situ burning as the ultimate recovery/disposal technique would be highly manpower intensive and would span an extended time period. The preferred technique of in situ burning while the blowout is still in progress for the 50 and 80% response levels is shown schematically in Figure 66.

Since the preferred response for all three levels of response capability incorporate in situ burning, there are no requirements for temporary storage or transfer of recovered oil. However, it is recognized that if in situ burning is not employed, temporary storage problems and transfer problems associated with the environmental conditions of this scenario are substantial, since the low air temperatures below the pour point of the oil will result in the solidification of the oil upon its recovery. Open top temporary storage containers would therefore be preferred, with an approach similar to the large snow berm described in the Beaufort Sea scenario worthy of consideration. In order to pump the oil, it would be necessary to either heat the oil to a temperature above its pour point or it would be necessary to cut the oil with some cutting stock. Both of these alternatives are likely impractical for the volume of oil associated with this scenario, therefore bulk material transfer systems would be required for transfer of the solidified oil.

Final disposal of the oil by in situ burning is clearly the preferred response technique since any mechanical recovery system requiring temporary storage and transfer of the recovered oil would face substantial problems operating at the low temperatures present in the area at the time of the spill. In addition, the cost of transporting oil which had been physically recovered to a final disposal site would be substantial, since there are no facilities for disposal in the local area at the present time, and none are expected to be installed by the time of the projected spill scenario since this spill is associated with the exploratory drilling phase of petroleum development. Any alternative disposal technique used would likely still have to dispose of the oil on scene due to the difficulty and cost associated with transporting the oil to a distant disposal site.

Logistics will be especially difficult in responding to this oil spill scenario since all existing facilities will be strained to support the personnel and equipment required for drilling the relief well. Activities associated with the spill response effort are expected to be subordinate to the primary activity of completing the relief well. The nearest established area, Fort Wainwright, is 50 miles from the blowout location since the blowout is situated 2 miles offshore within the Barrier Island system. Personnel and equipment

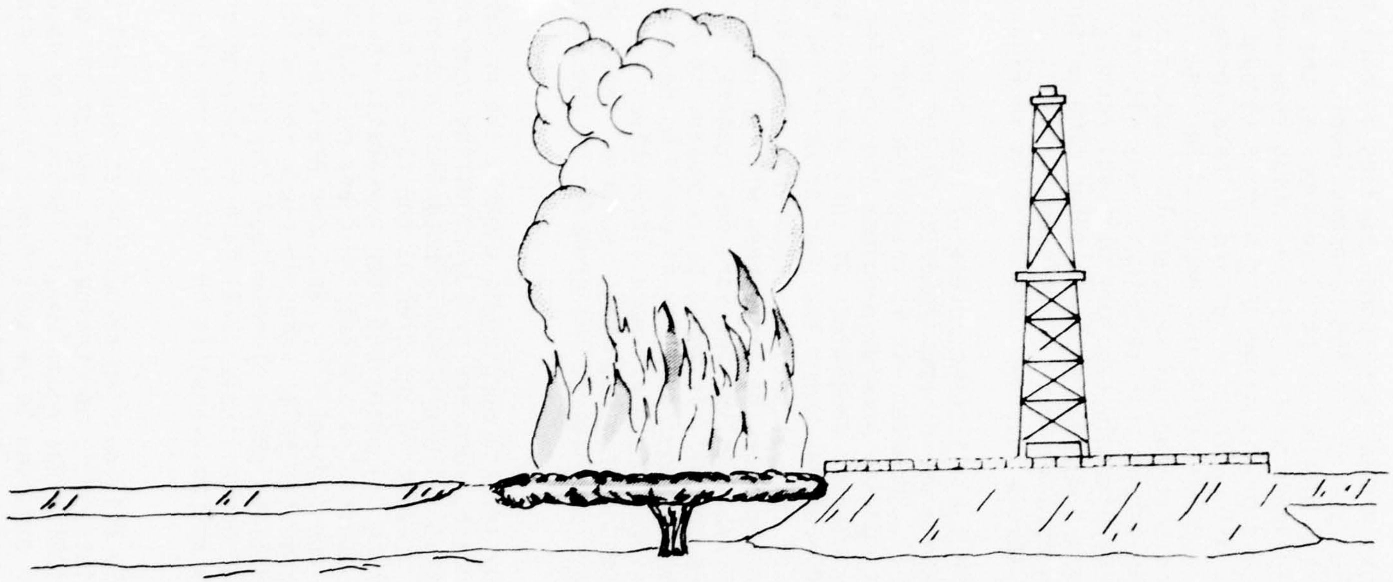


Figure 66. Schematic Representation of In Situ Burning While the Blowout is in Progress to Achieve the 50 and 80% Response Capability for the Chukchi Sea Scenario

would have to be flown to Fort Wainwright, and subsequently transferred to the scene. It is conceivable that a landing strip could be constructed near the spill site by pumping water onto the ice surface and subsequently grading the surface. This would enable fixed wing aircraft such as the Hercules C-130 to play a major role in the logistics effort. A runway length of 4,000 ft would be required for the Hercules. Because of the great demand on all existing facilities at the site, all personnel shelters, food, clothing, communications equipment, transportation equipment, and support facilities related to the oil spill response effort would have to be flown to the site.

Ancillary functions again are independent of the level of response effort, with weather forecasts and ice forecasts required to assure the safety of response operations, and radio beacons required for marking the spill site to assist aircraft in locating the site in the event of adverse weather conditions. All members of the response team should be equipped with individual emergency equipment. Medical facilities available at Fort Wainwright and Prudhoe Bay will be pressed into service when needed. Personnel requiring additional medical attention can be flown from Fort Wainwright to Fairbanks or Anchorage within a few hours. One light helicopter must be dedicated to the emergency evacuation function at all times.

The preferred spill response techniques for three levels of response capability for the Chukchi Sea oil spill scenario are summarized in Table 22. The equipment and labor associated with the preferred oil spill responses are summarized in Tables 23, 24, and 25 for the 25, 50 and 80% response levels respectively.

TABLE 22. SUMMARY OF PREFERRED SPILL RESPONSE TECHNIQUES FOR THE CHUKCHI SEA SPILL SCENARIO

Function	25% Response Level	50% Response Level	80% Response Level
Detection	Observation by operating personnel on the drill rig	Same	Same
Surveillance	None	None	Drill holes in ice to determine presence or absence of oil
Containment	Natural	Natural	Natural
Recovery	Gain access to oil through natural processes; burn in situ	Same	Same
Storage	None	None	None
Transfer	None	None	None
Disposal	Burn in situ after blowout is arrested	Burn in situ; start while blowout is underway	Same
Logistics	Through Ft. Wainwright to spill site; construct ice landing strip near site for Hercules aircraft; all support facilities flown to site	Same	Same
Ancillary	Weather and ice forecasts; marking beacons; communications equipment	Same	Same
Emergency Evacuation	Dedicated helicopter, personnel emergency beacons	Same	Same

TABLE 23. EQUIPMENT AND LABOR ASSOCIATED WITH A 25% RESPONSE TO SCENARIO NO. 2 - CHUKCHI SEA

A. SURVEILLANCE

None

B. CONTAINMENT

None

C. RECOVERY (10 days for in situ burning after well is capped)

1 Operations Manager
2 Supervisors
2 Equipment Operators
8 Laborers
1 Bulldozer (D-9 or similar)
1 Front End Loader
Diesel Fuel for In Situ Burning (1,700 gal in 50 gal drums)
100 Incendiary Devices (Thermite, Phosphorus, or Kontax)

Logistics for Recovery

3 Shelters at Base Camp (30 x 10 ft trailers)
2 Warm Up Shelters on Site (30 x 10 ft trailers)
1 Crew Transport Vehicle
4 50,000 BTU Heaters
Kerosene at Base Camp
Water and Expendibles at Base Camp
Miscellaneous
Consumables by Personnel
6 7.5 kva Generators (500 lb each)
6 Sets of 1,000 w Lights
30 kva Generator (500 lb)
Logistics to Transport All Equipment to Site

RECOVERY (In situ burning in Spring for 10 days)

1 Operations Manager
3 Laborers
100 Incendiary Devices (Thermite, Phosphorus or Kontax)

Logistics for Recovery

Helicopter
Food and Lodging

TABLE 23. EQUIPMENT AND LABOR ASSOCIATED WITH A 25% RESPONSE TO SCENARIO NO. 2 - CHUKCHI SEA (Continued)

D. STORAGE

None

E. TRANSFER

None

F. DISPOSAL

In Situ Burning

G. LOGISTICS (Landing strip construction - 6 days)

1 Supervisor
4 Equipment Operators
1 Grader
2 D-9 Cat
3 50 gpm Self Priming Portable Pumps

LOGISTICS (Road from site to base camp - 2 days)

2 Equipment Operators
1 Grader
1 Bulldozer (D-9 or similar)

H. ANCILLARY

2 Radio Beacons, Aircraft Navigation Frequency
Communications Equipment

I. EMERGENCY EVACUATION

1 Support Helicopter
13 Individual Emergency Beacons

TABLE 24. EQUIPMENT AND LABOR ASSOCIATED WITH A 50% RESPONSE TO SCENARIO NO. 2 - CHUKCHI SEA

A. SURVEILLANCE

None

B. CONTAINMENT

None

C. RECOVERY (Crew on scene for 50 days)

2 Operations Managers
2 Supervisors
10 Laborers
40 Barrels of Diesel Fuel (50 gal drums)
100 Incendiary Devices (Thermite, Phosphorus or Kontax)
Logistics for Recovery

3 Warm Up Shelters on Site (30 x 10 ft trailers)
Logistics to Get All Equipment and Men to Site
3 7.5 kva Generators (500 lb each)
Crew Transport Vehicle
Miscellaneous
6 50,000 BTU Heaters
Consumables by Personnel
3 Shelters at Base Camp (30 x 10 ft trailers)
Water and Expendables at Base Camp
Kerosene at Base Camp
30 kva Generator (500 lb)

D. STORAGE

None

E. TRANSFER

None

F. DISPOSAL

In Situ Burning

G. LOGISTICS

Same as 25% Response

TABLE 24. EQUIPMENT AND LABOR ASSOCIATED WITH A 50% RESPONSE TO SCENARIO NO. 2 - CHUKCHI SEA (Continued)

H. ANCILLARY

2 Radio Beacons, Aircraft Navigation Frequency
Communications Equipment

I. EMERGENCY EVACUATION

1 Support Helicopter
14 Individual Emergency Beacons

TABLE 25. EQUIPMENT AND LABOR ASSOCIATED WITH AN 80% RESPONSE TO SCENARIO NO. 2 - CHUKCHI SEA

A. SURVEILLANCE (25 days for operation, 5 days setup and breakdown)

1 Operations Manager
2 Supervisors
2 Equipment Operators
4 Laborers
2 Nodwell Drills (2,500 lb each)
2,000 Surface Markers (disposable cards)

Logistics for Surveillance

2 Warm Up Shelters at Site (30 x 10 ft trailers)
4 7.5 kva Generators (500 lb each)
4 50,000 BTU Heaters
6 Sets of 1,000 w Lights
Logistics to Fly Personnel and Equipment to Site
1 Crew Transport Vehicle
3 Shelters at Base Camp (30 x 10 ft trailers)
Consumables by Personnel
30 kva Generator (500 lb)
Kerosene at Base Camp
Water and Expendables at Base Camp
Expendables

B. CONTAINMENT

None

C. RECOVERY (Drill holes in solid ice to burn oil in situ - 8 days)

50% Response List
1 Operations Manager
1 Supervisor
2 Equipment Operators
4 Laborers
2 T-5 Downhole Drill Master (85,000 lb each)
Diesel Fuel (50 gal drums)
100 Incendiary Devices (Thermite, Phosphorus, or Kontax)

Logistics for Recovery

2 Warm Up Shelters On Site (30 x 10 ft trailers)
2 7.5 kva Generators On Site (500 lb each)
4 50,000 BTU Heaters
1 Crew Transport Vehicle
3 Shelters at Base Camp (30 x 10 ft trailers)
Miscellaneous
Kerosene at Base Camp
30 kva Generator at Base Camp (500 lb)
Water and Expendables at Base Camp

TABLE 25. EQUIPMENT AND LABOR ASSOCIATED WITH AN 80% RESPONSE TO SCENARIO NO. 2 - CHUKCHI SEA (Continued)

RECOVERY (In situ burning during spring - 30 days)

1 Operations Manager
1 Supervisor
1 Laborer
1 Helicopter
1,000 Incendiary Devices (Thermite, Phosphorus or Kontax)

D. STORAGE

None

E. TRANSFER

None

F. DISPOSAL

In-Situ Burning

G. LOGISTICS

Same as 25% Response

H. ANCILLARY

2 Radio Beacons, Aircraft Navigation Frequency
Communications Equipment

I. EMERGENCY EVACUATION

1 Support Helicopter
9 Individual Emergency Beacons

Scenario 3 - Norton Sound

Spill Mode

The Norton Sound oil spill scenario consists of a tanker casualty resulting in the instantaneous release of 50,000 barrels of crude oil 50 miles off the coast of Nome in April in the presence of 3 ft thick decaying and moving hummocky ice. This scenario envisions the use of a marine transportation system for the transport of crude oil from one of the northern reservoirs which would include the Beaufort Sea, the Chukchi Sea, Kotzebue Sound and Norton Sound. The casualty is based on the tanker rupturing four of its cargo holds while ramming through a pressure ridge. The entire release of 50,000 barrels of crude oil will occur while the tanker is still at the pressure ridge. Therefore, for the purposes of this study, the release will be considered as instantaneous.

Environmental Conditions

At the time of this spill in early April the ice growth season in Norton Sound is nearing its end and the period of ice decay begins. Ice in the area, consisting primarily of large ice floes, will decrease in concentration from 90% to 75% over the month of April. The mean thickness of the ice field in the month of April will be 43 inches, and the ice field will be interspersed with ridges, rafted ice, hummocks, and open water leads. In the month of May, ice thicknesses are typically 3 ft and ice concentrations will decline by the end of May to about 25%. The ice begins to clear out in early June, and from July through October the area is typically ice-free.

During the month of April mean monthly air temperatures are still well below freezing at 19.2°F, rising above freezing to 34.3°F in May, and remaining above 40°F from June through September. Water temperatures remain at 28°F during the winter months, and increase through the spring to a summertime high of about 50°F nearshore. Water depths in the area are typically in the 7 to 12 fathom range, while water currents of 0.5 to 1 knot curve along the coastline with surface currents entering the sound from the south and circulating around to exit in a northwesterly direction. The tidal range at Norton Sound is about 1 ft.

During the month of April there are from 13 to 17 hours of sunlight per day in Norton Sound. The period of continuous sunlight begins around the middle of May and continues through the month of July. During the month of April there is a 13% probability that there will be obstructions to vision resulting in a reduction in visibility to 6 miles or less, with 11% due to fog and 2% due to blowing snow. One day of heavy fog, defined as fog causing a reduction in visibility to 1/4 mile or less,is typical in April. During the month of May there is a 12% probability that there will be obstructions to vision entirely due to fog, and 4 days of heavy fog are typical. Obstructions to vision then increase in the month of June to the extent where there is a 15% chance of obstructions to vision due to fog, and a 1% chance of obstructions

to vision due to smoke or haze resulting in a total obstruction to vision 16% of the time. Four days of heavy fog are typical for the month of June. During the month of July there is a 20% chance of obstructions to vision due to fog and 1% due to smoke or haze resulting in a 21% probability of obstructions to vision. Heavy fog can also be expected for 4 days in the month of July.

Precipitation in the month of April typically consists of 8 inches of snow. In the month of April there is a 35% chance that there will be 13 to 24 inches of snow on the ground, and a 32% chance that there will be 25 to 36 inches of snow on the ground. The typical snowfall for the month of May is 2 inches, and there is a 40% probability that there will be little or no snow on the ground, a 19% probability that there will be 1 to 3 inches of snow on the ground, a 12% probability of 4 to 6 inches of snow on the ground, and a 12% probability of 7 to 12 inches of snow on the ground. The mean snowfall for the month of June is 1 inch, and there is a 98% probability that there will be only traces of snow remaining on the ground in June. Winds during the month of April are typically 11 mph from a northerly direction, reducing to 10 mph from a northerly direction in May, and holding at 10 mph but from a west-southwesterly direction in June and July. While dependent upon surrounding ice conditions in the spring, there is a 5% probability of wave heights being greater than or equal to 5 ft in the summertime at Norton Sound. The storm history of Norton Sound reveals that typically one storm per month can be expected through the months of April, May and June. The Norton Sound area has experienced seismic waves recording greater than 6.0 on the Richter scale, and it is considered to have a potential for maximum damage to structures due to earthquakes.

Spill Behavior

For the purposes of this study, the release of the 50,000 barrels of crude oil from the four ruptured holds of an icebreaking crude oil tanker while operating in a ramming mode through a field of pressure ridges is assummed to occur instantaneously. Upon release, this oil will concentrate in areas in which it can flow most freely such as open water leads, crack systems, and the broken ice channel of the ship's track. It is assumed that 80% of the released oil will locate in the ship's track and intermingle there with the brash and broken ice pieces present, concentrating to the thickness of the broken ice cover. It is therefore estimated that the oil will be contained in the ship's track to a thickness of 43 inches between the broken ice pieces. The remaining 20% of the oil is assumed to spread over or under the ice edges of the ship's track to a nominal thickness of 1 inch. The area affected by the oil slick will therefore be about 150 ft wide and 4,300 ft long. Within a period of 2 days it is anticipated that the forces exerted on the ice field by wind and currents will close the ship's track, with the oil either being sandwiched within the resulting pressure ridge, rubble ice field, or rafted ice field, or forced above and below the level ice. It is also assumed that water currents in the area are not sufficient to cause a significant transport of the oil beneath the ice, therefore the oil will remain locked within the deformed icc field

and will be transported with it. At the time of the spill, the ice growth season is nearing its end and the period of ice decay begins. Ice in the area, consisting primarily of large ice floes, will decrease in concentration to 75% by the end of April. The oil that was locked within the broken ice field will begin to spread on the open water. As more open water becomes available and the oil is released from the ice, the spill will encompass a greater area. By early May when the ice begins to rapidly deteriorate, ice concentrations will decrease to about 50%, with only 20% of the region consisting of large ice floes. As the ice moves more freely, driven by winds and currents, the oil will be further distributed to encompass a greater area. By the end of May ice concentrations will have declined further to 25%, and the oil is assumed to no longer be contained by the broken ice field to any significant extent. The areal coverage at this point will correspond to the open water termianl slick thickness, assumed to be 0.28 inches. Upon reaching open water conditions, the transport of the oil slick will be governed by winds, waves, and currents. By early June, it is expected that any remaining oil will be in discrete patches, or in the few remaining ice floes.

The estimated behavior of the spilled oil following its release is summarized in Figure 67 in terms of the areal coverage of the spill, the volume of the spilled oil entrained in the ice, and the volume of recoverable oil remaining,all as a function of time. The gradual reduction in the volume of recoverable oil remaining results from the weathering of the oil, primarily evaporation and dissolution, which would result in a maximum loss to the slick of 33% of the volume spilled leaving 33,500 barrels of oil remaining for possible recovery. As the ice concentration decreases and the oil approaches open water spill conditions, the surface area of the oil exposed to the atmosphere and to the water column increases, resulting in continued weathering of the oil.

Spill Response

The oil spill will be detected by shipboard personnel through visual observation as the vessel is backing out of the pressure ridge. The casualty will be reported to the Coast Guard and to the nearest population center of Nome by ship's radio.

Initial onsite surveillance will be provided by the crew of the stricken vessel. While the ship is drifting with the ice pack, observations will be made as to the extent and the initial distribution of the spilled oil. It is assumed that the vessel will remain with the ice pack until it is relieved by another vessel. The need for extensive areal surveillance to relocate the contaminated area is therefore eliminated. Subsequent surveillance will be provided by aircraft and other marine vehicles such as a relief ice-breaking tanker or a Coast Guard icebreaker. Standard tugs and buoy tenders will not have the capability to operate in the ice conditions present at the time of the spill. The transit time for a Coast Guard icebreaker to arrive from Kodiak is assumed to be seven days. If it does not snow, and if the ship's track does not close rapidly, the limits of the spill within the

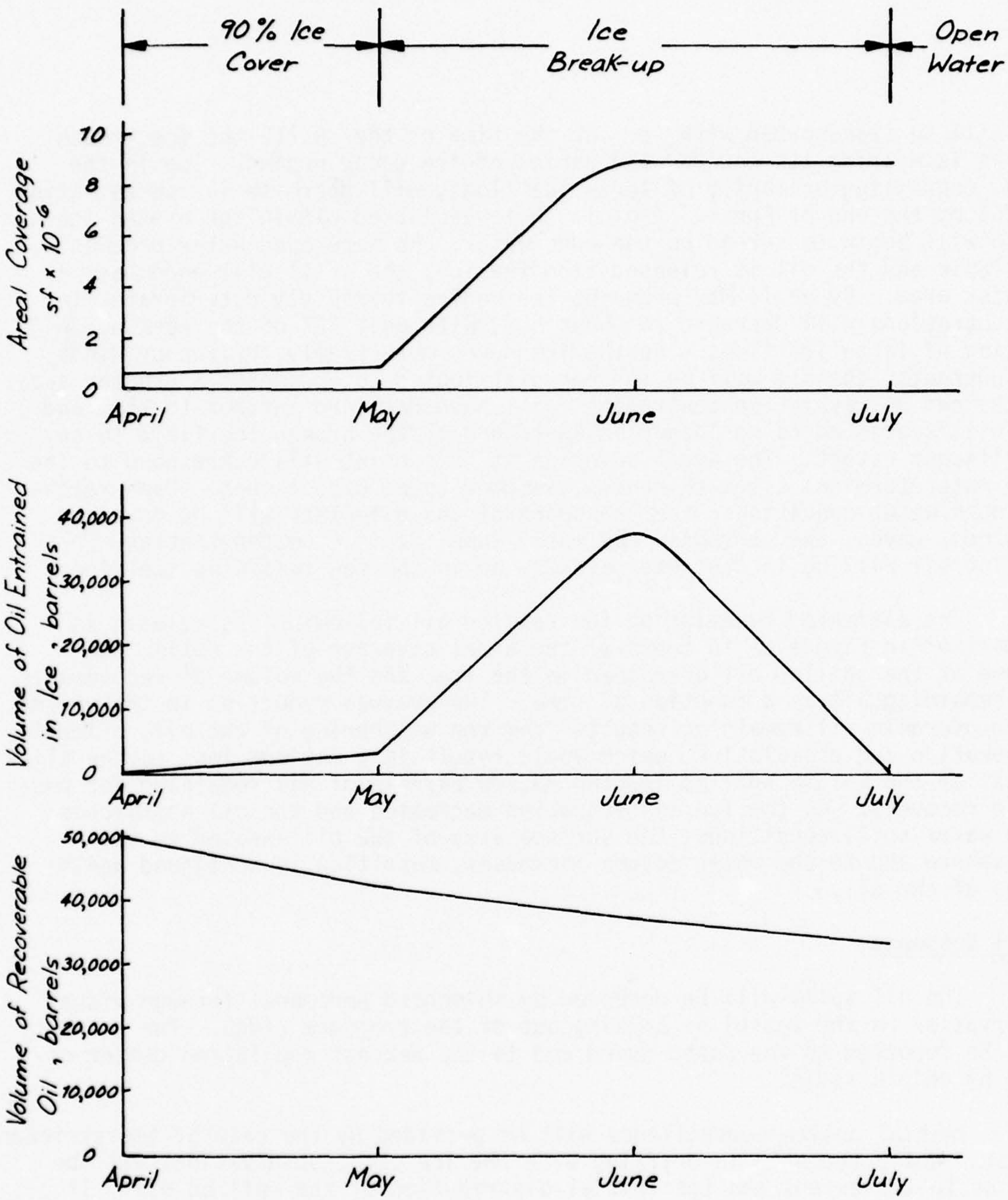


Figure 67. Summary of the Projected Behavior of Oil Spilled in the Norton Sound Scenario in Terms of Areal Coverage, Volume of Oil Entrained in Ice, and the Volume of Recoverable Oil Remaining.

ship's track could be detected visually by air. In order to locate oil beneath snow and ice, electronic devices including pulsed laser fluorometers, impulse radars and microwave detectors conceivably have some limited capability, but none of these techniuqes have been demonstrated in these conditions. The preferred approach for defining the limits of the spill is to use the spill response team upon its arrival at the site to determine the presence or absence of oil beneath the ice cover by systematically drilling holes through the ice with ice drills or augers. It has been estimated that the limits of the spill could be satisfactorily defined by five teams of four men working for three days on this task.

Since most of the released oil is expected to be distributed within the broken ice field of the ship's track contained within the boundaries of the adjacent solid ice cover, a substantial amount of natural containment will occur. It has been estimated that at least 80% of the spill is likely to be contained within the ship's track. No other containment measures are therefore judged necessary for this scenario. Since there presently is no apparatus capable of containing spilled oil in large moving ice fields, the remainder of the spill response effort is geared towards completing spill response operations before extensive breakup of the ice occurs.

For the 25% response level, it is judged that there is adequate access to 25% of the oil in concentrated pools among the broken ice pieces so as to allow in situ burning as the preferred response for this level as shown schematically in Figure 68. The preferred technique is then to fly a spill response team by helicopter from Nome to the spill site to initiate in situ burning of the concentrated pools of oil in the ship's track. Once the tanker has cleared the immediate area of the spill, the thick oil in the ship's track will be ideal for maintaining in situ combustion. Therefore, for the 25% response level, there is no requirement for physical recovery, temporary storage, or transfer of the oil. The disposal function for this response level is satisfied by the in situ combustion of the oil.

In order to increase the response level from 25 to 50%, the preferred response is to undertake a manpower intensive operation whereby hand held gasoline powered saws and augers would be used to cut through the compacted rubble ice field to gain access to the concentrated pools of oil. Since there are 30 days available for recovering the oil from the time of the spill to the time of ice breakup, and since it takes seven days for the icebreaker to arrive onscene to serve as the base for spill response operations, twenty three days remain to recover the required additional 25% of the oil. Based on the assumption that two barrels of oil could be recovered from a concentrated oil pool by a four man team in one hour, twelve teams working continuously for a 23 day time period would be required to recover the additional 13,500 barrels of oil. Allowing for two shifts of operation and allowing two days for bad weather conditions, 28 teams would be required to achieve the 50% response level. While this technique appears to parallel the approach used in gaining access to two barrel pockets of concentrated oil in the Beaufort Sea scenario, the in situ burning approach for disposal used in the

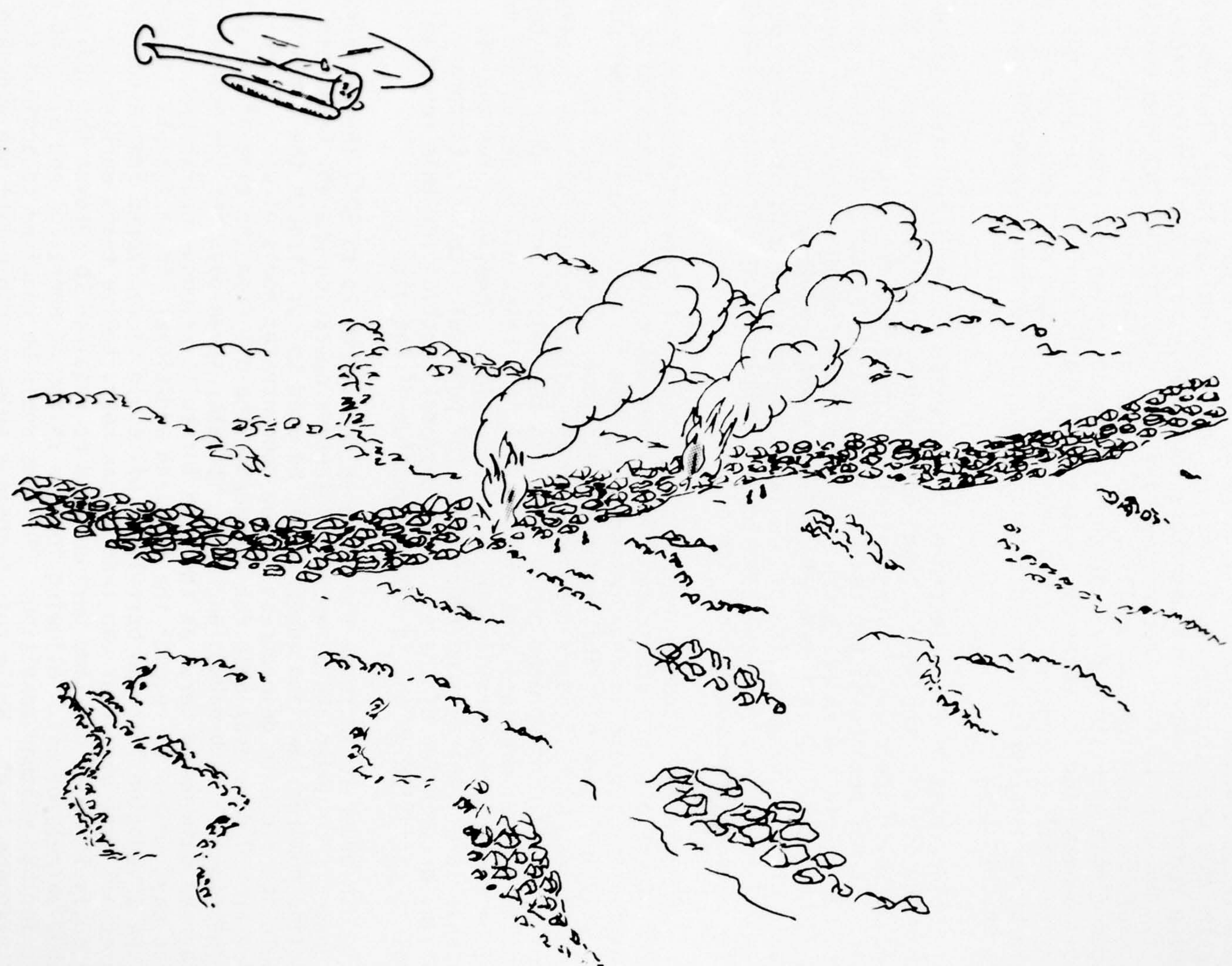


Figure 68. Schematic Representation of In Situ Burning of Oil Spilled in the Broken Ice Field of the Ship's Track to Achieve the 25% Response Level for the Norton Sound Scenario.

Beaufort Sea scenario is not judged applicable to the Norton Sound scenario. The major distinctions are the facts that the Beaufort Sea response was in stable level ice conditions where a drilled hole has limited freeboard, and the drilled holes were of large diameter. In situ combustion was therefore judged to be possible under these conditions. In contrast, the Norton Sound scenario is concerned with reaching pockets of concentrated oil in pressure ridges and rubble ice fields where the freeboard is substantially greater than would be the case in level ice conditions, and, in addition, the hand held ice drill or ice auger will result in a hole of far smaller diameter. The small hole combined with the high freeboard makes it unlikely that in situ combustion could be maintained. It is therefore judged that it will be necessary to physically remove the oil from the drilled holes in the Norton Sound scenario in order to achieve the 50% response level. The preferred approach for recovery is to remove the oil from the hole by direct suction using conventional pumps, and by the use of adsorbent materials. In order to further increase the response level to 80%, it has been judged that a special oil/ice recovery vessel would be required having the capability to separate out oil which is intermingled within a broken ice field, and to clean oil contaminated ice pieces. A development program would be required for such a vessel since no vessel having this capability presently exists.

As previously indicated, the 25% response level requires no oil transfer capability. For the 50% response case, however, the oil would have to be transferred from the holes in the ice to temporary storage bladders or tanks, and then further transferred into another system for disposal. Pumping systems would therefore have to be capable of pumping oils of very high viscosity. It is also possible that there may be times when the transfer operation would have to be temporarily terminated when temperatures dipped below the pour point of the oil of -5°F for some period of time.

Temporary storage for the 25% of the oil gathered by direct suction in the 50% response case will require some form of temporary storage between the period of recovery and the time of ultimate disposal. For pools of oil in near proximity to the icebreaker which is used as the base of operations, it may be possible to pump recovered oil directly to the icebreaker's holding tanks. For locations more distant from the icebreaker, the preferred response is to use small portable bladders mounted on sleds and transported by snow vehicles. For the 80% resoonse level, it is assumed that the vessel would be capable of separating the oil from ice and water, and would have the necessary capacity for temporary storage. Assuming that disposal would take place concurrently with the cleanup operation, the requirements for storage capacity on the special oil/ice recovery vessel could be as little as 1,000 barrels, depending upon the recovery and disposal capacities of the equipment on the vessel.

As previously indicated, the disposal technique for the 25% response level consists of in situ burning. In order to reach the 50% response level, means must be provided for disposing of the oil which has been physically recovered and placed in temporary storage. Alternatives available include

the use of a sled mounted oil field type open flame burner, or open pit burners. It may also be possible to transfer recovered oil to a relief tanker if such were available. However, since this response scenario was based upon a response independent of a relief tanker, the preferred response consists of disposing of the physically recovered oil onscene through the use of an open flame burner as schematically depicted in Figure 69. For the 80% response level, the special oil/ice recovery vessel is assumed to be complete with some disposal technique such as an open flame burner or boilers designed to use recovered oil as part of its fuel. The use of this vessel to acheive the 80% response level is shown conceptually in Figure 70.

For oil spill response logistics, it is assumed that the closest available icebreaker will be deployed to the spill site as soon as the spill is reported.

While the icebreaker is enroute, equipment and personnel required for the 25% response case will be flown to a staging area at Nome, and then transferred to the spill site by helicopter. Aside from the helicopter support, and lodging provided at Nome, no specialized logistics requirements must be met for the 25% response level. The manpower intensive effort required to achieve the 50% response level would require the use of the icebreaker, and possibly the stricken tanker or a relief tanker, for berthing and galley facilities. Several helicopters will be required to support the response activities.

Ancillary functions required for support of the oil spill response effort are similar to the requirements for the preceding scenarios, including weather and ice forecasts and emergency beacons for personnel working on the ice. One helicopter must be dedicated to rescue and emergency evacuation purposes throughout the term of spill response activities. Paramedical facilities will be available on the icebreaker, and emergency medical cases could be flown by helicopter to Nome, and transferred to Fairbanks or Anchorage if required.

The preferred spill response techniques for the Norton Sound oil spill scenario are summarized in Table 26 for each of the three response levels. The equipment and labor associated with the preferred oil spill responses are further defined in Tables 27, 28, and 29 for the 25, 50 and 80% response levels respectively.

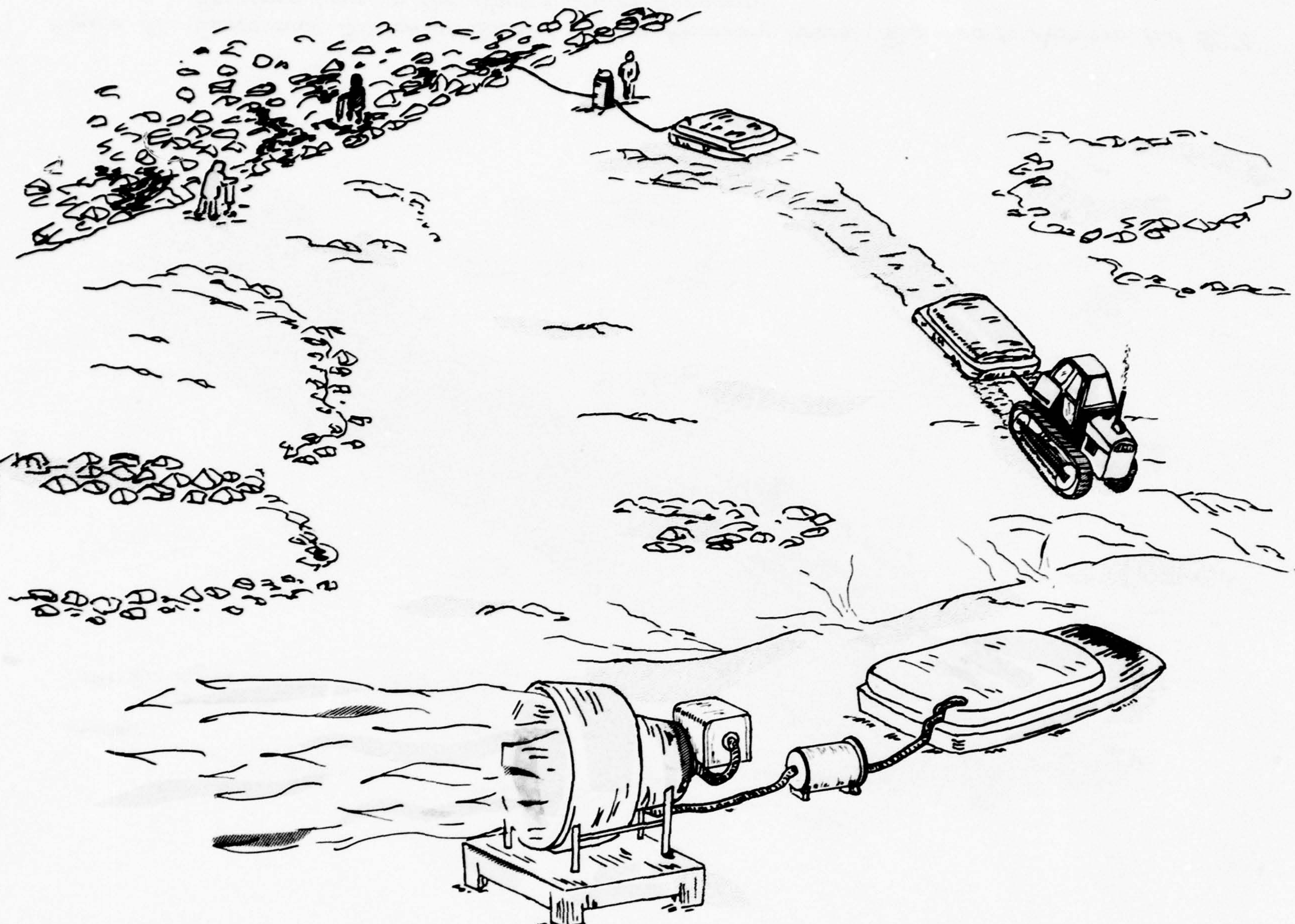


Figure 69. Schematic Representation of the Additional Response Activities Required to Achieve the 50% Response Level for the Norton Sound Scenario

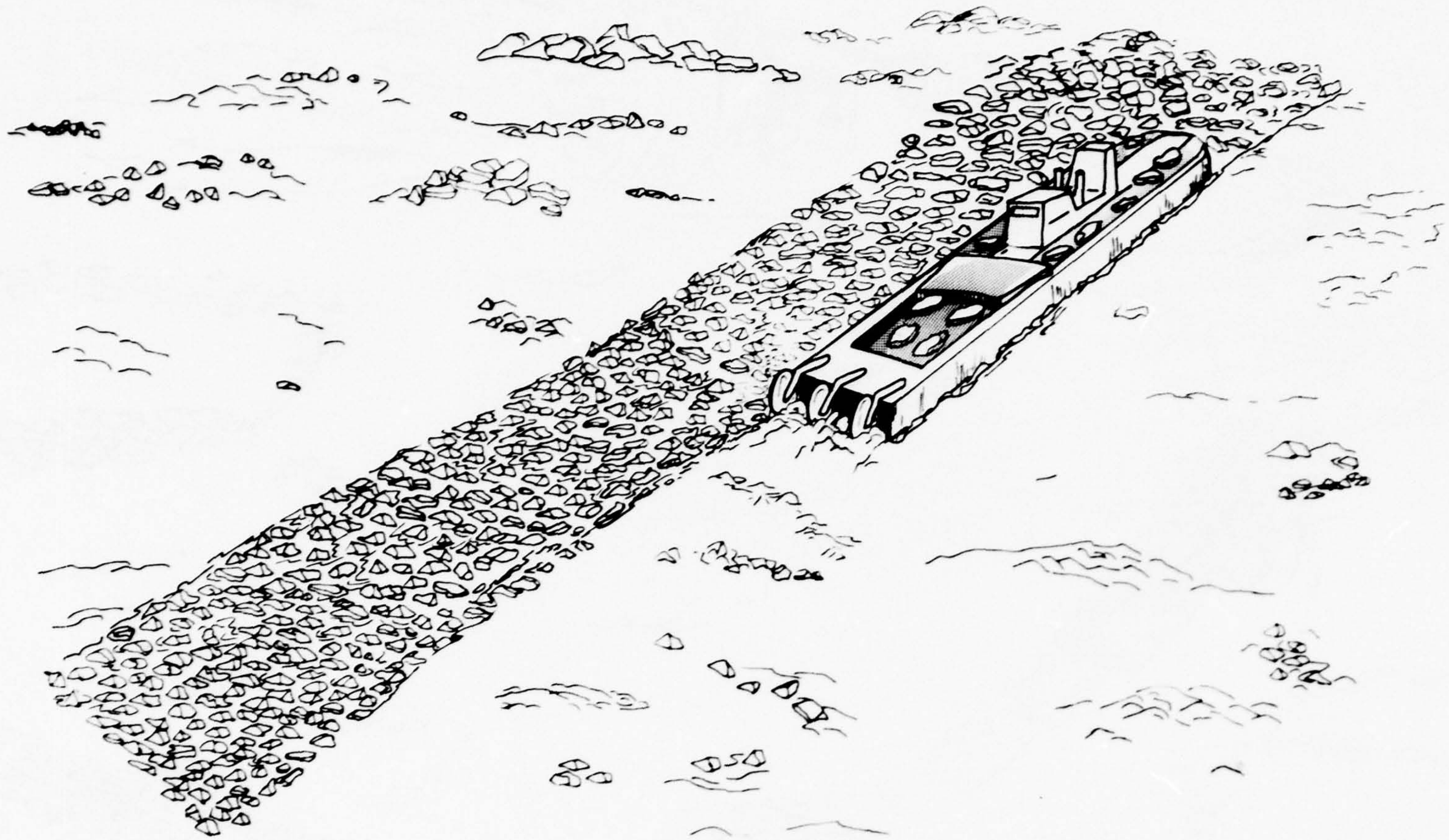


Figure 70. Conceptual Sketch of Special Oil/Ice Recovery Vessel Required to Achieve the 80% Response Level in the Norton Sound Scenario.

TABLE 26. SUMMARY OF PREFERRED SPILL RESPONSE TECHNIQUES FOR THE NORTON SOUND SPILL SCENARIO

Function	25% Response Level	50% Response Level	80% Response Level
Detection	Visual observation by ship's crew	Same	Same
Surveillance	None	Drill holes in ice to determine presence of absence of oil	None
Containment	Natural	Natural	Natural
Recovery	In situ burning	Drill through ice to oil pools and remove oil by direct suction	Special oil/ice recovery vessel
Storage	None	Portable bladder tanks	Special oil/ice recovery vessel
Transfer	None	Portable pumps	Special oil/ice recovery vessel
Disposal	Burn in situ	Burn in situ and with open flame burner	Special oil/ice recovery vessel
Logistics	Helicopter transportation from Nome to spill site	Same plus use of icebreaker or tanker as field base; helicopters between Nome and site	Same plus getting special oil/ice recovery vessel to the site
Ancillary	Weather and ice forecasts; marking beacons	Same	Same
Emergency Evacuation	Helicopter; personnel emergency beacons	Helicopter and paramedical facilities of icebreaker	Same as 25% level

TABLE 27. EQUIPMENT AND LABOR ASSOCIATED WITH A 25% RESPONSE TO SCENARIO NO. 3 - NORTON SOUND

A. SURVEILLANCE

None

B. CONTAINMENT

None

C. RECOVERY (3 days to burn oil, 2 days setup and breakdown)

1 Operations Manager
1 Supervisor
2 Laborers
1,000 Incendiary Devices (Thermite, Phosphorus, or Kontax)

Logistics for Recovery

1 Helicopter

D. STORAGE

None

E. TRANSFER

None

F. DISPOSAL

In Situ Burning

G. ANCILLARY

Communications Equipment

H. EMERGENCY EVACUATION

None

TABLE 28. EQUIPMENT AND LABOR ASSOCIATED WITH A 50% RESPONSE TO SCENARIO NO. 3 - NORTON SOUND

A. SURVEILLANCE (3 days on scene)

1 Operations Manager
5 Supervisors
15 Laborers
5 Hand Held Powered Augers, 6 in x 6 ft bits
3 Chain Saws, 6 ft blades
500 Disposable, Buoyant Surface Markers

Logistics for Surveillance

USCG Polar Icebreaker (7 days from Kodiak to Norton Sound)
USCG Polar Icebreaker (3 days on scene)
Consumables by Personnel

B. CONTAINMENT

None

C. RECOVERY (23 days for response on scene)

25% Response List
2 Operation Managers
28 Supervisors
84 Laborers
14 Hand Held Powered Augers, 6 in x 6 ft bits
14 Chain Saws, 6 ft blades

Logistics for Recovery

All Laborers 14 days of time (7 days to and from scene on icebreaker)
14 Sleds
1 Snow Tracked Vehicle
10 Sets of 1,000 w Lights
5 7.5 kva Generators (500 lb each)
Consumables While in Transit
Consumables While on Scene
Cleanup of Equipment
Miscellaneous

D. STORAGE

14 500 Gallon Bladder Tanks

E. TRANSFER

14 Self-Priming Portable Pumps, 200 gpm @ 150 ft discharge

TABLE 28. EQUIPMENT AND LABOR ASSOCIATED WITH A 50% RESPONSE TO SCENARIO NO. 3 - NORTON SOUND (Continued)

F. DISPOSAL

1 Open Flame Burner System for 125 bbl/hr (6,000 lb)

G. ANCILLARY

Communications Equipment

H. EMERGENCY EVACUATION

114 Individual Emergency Beacons

TABLE 29. EQUIPMENT AND LABOR ASSOCIATED WITH AN 80% RESPONSE TO SCENARIO NO. 3 - NORTON SOUND

A. SURVEILLANCE

Same as 50% Response

B. CONTAINMENT

None

C. RECOVERY (On scene, logistics and breakdown for 40 days)

25% Response List
2 Operations Managers
4 Supervisors
10 Laborers
Oil/Ice Recovery Vessel

Logistics for Recovery

USCG Icebreaker Support
2 Invader Class Tugs
Consumables by Personnel
Miscellaneous

D. STORAGE

Part of Oil/Ice Recovery Vessel

E. TRANSFER

Part of Oil/Ice Recovery Vessel

F. DISPOSAL

Part of Oil/Ice Recovery Vessel

G. ANCILLARY

Communications Equipment

H. EMERGENCY EVACUATION

None

Scenario 4 - Navarin Basin

Spill Mode

The oil spill scenario selected for the Navarin Basin area of the Bering Sea is also related to the use of a marine transportation system for the transport of crude oil from one of the northern or northwestern reservoirs including the Beaufort Sea, the Chukchi Sea, Kotzebue Sound or Norton Sound. This spill scenario assumes the rupture of four cargo holds of an icebreaking crude oil tanker due to interaction with ice, and the release of 50,000 barrels of crude oil in the broken ice field remaining in the ship's track. This spill is selected to occur in early March in the presence of a 2 ft thick hummocky, moving ice field.

Environmental Conditions

Since detailed environmental data is unavailable for the Navarin Basin area, the environmental conditions summarized below are based primarily on data obtained from the Northeast Cape station on St. Lawrence Island, which is located 160 miles northeast of the selected spill site. This environmental data for Northeast Cape was adjusted based on a consideration of the climatological data obtained for the Pribilof Islands and Norton Sound. The description of the environmental conditions for the Navarin Basin scenario are therefore significantly more approximate than is the case for the other five arctic spill scenarios.

Ice conditions in the Navarin Basin area during March are expected to consist of a 2 ft thick moving ice field with pressure ridges having keel drafts of up to 10 ft. Ice concentrations typically reach 90%. Localized motion of the ice would be governed by wind stresses and water currents, with leads opening and closing, and ice concentrations variable, however, there will be a bulk transport of the entire ice field in a southerly direction at a rate of 50 miles per month. During the month of April, ice concentrations will diminish to about 75%, and greater localized movement of the ice will occur. The ice will start to deteriorate to a significant extent at the beginning of May, with the ice concentration dimishing to 40% by the end of May.

Mean air temperatures for the months of March, April and May are estimated to be 9, 17 and 32°F respectively. Minimum temperatures for the same three months are estimated to be -25, -20 and 2°F respectively. With the high concentration of ice in the area, the water temperature is expected to be 28°F in March, warming to about 38°F in May. Water depths in the area will be in the 30 to 40 fathom range, well in excess of any draft requirements for commercial shipping. Surface currents are expected to be minor in the area during the period of significant ice cover.

Based on data obtained for Northeast Cape, it is estimated that during the months of March and April visibility will be obstructed due to fog about 15 to 20% of the time, increasing to about 25% of the time in May. The period

of sunlight in this area extends for about 12 hours per day in March, increasing to 15 hours per day in April, and 18 hours per day by the end of May.

In March it is estimated that there is a 40% probability that there will be 13 to 24 inches of snow on the ice, and a 28% probability that there will be 7 to 12 inches of snow on the ice. In April, it is estimated that there is a 46% probability that there will be 25 to 36 inches of snow on the ice, a 34% probability that there will be 13 to 24 inches of snow on the ice, and a 20% probability that there will be 7 to 12 inches of snow on the ice. Typical monthly snowfalls are projected to be 11 inches in March, 11 inches in April, and 4 inches in May. Winds are projected to be in the range of 10 to 12 mph from the north in March and April, and from the east in May. Relatively little wave motion is expected in the area because of the partial ice cover. It has also been estimated that on the average there would be less than one storm per month for each of the months of March, April, and May.

Spill Behavior

Based on the assumption that the deck watch of the tanker detects the spill within 20 minutes after the initial release of the oil, the oil will be spread over a length of 1.3 nautical miles in the 150 ft wide broken ice track made by the transit of the tanker. Due to the partial containment of the oil by the broken ice field, it is assumed that the nominal oil thickness between broken ice pieces within the ship's track will be 18 inches. Oil which spreads beneath the adjacent ice cover will have a nominal thickness of 1 inch. The dynamics of the ice field will govern the behavior and distribution of the spilled oil. Within a period of a few days, forces exerted on the ice by winds and currents will cause the ship's track to close and the oil will be squeezed beneath and on top of the adjacent ice cover and incorporated into rafted ice, hummocks, and pressure ridges. Since the ice concentration during the month of March in the area is relatively constant at about 90%, the oil will move primarily in bulk with the ice through the month of March, with localized spreading of the oil being relatively limited. In April, when ice concentrations in the area are expected to decrease to about 75%, the oil will be gradually released from the ice field, spreading to the open water areas, and further increasing the areal coverage of the spill. Free-floating oil will come in contact with deteriorating unoiled ice, and the oil will penetrate into the deteriorating ice to an amount as great as 30% of the spill volume. As the ice becomes more mobile, the slick will separate into discrete patches.

In early May when the concentration of the ice field is estimated to decline to the 40% level, most of the oil will be released from the ice field and behave virtually as it would under open water conditions. The terminal open water thickness of the oil slick is estimated to be 0.28 inches. The rate of evaporation will increase as the ice conditions deteriorate, and the oil spreading increases such that by the end of May 33% of the spilled oil is projected to be lost to weathering processes. By the end of June, the spill site will be ice free, and any remaining oil will consist primarily of heavy end components which will eventually form tar balls.

Figure 71 summarizes the estimated projected behavior of the oil spilled in the Navarin Basin scenario in terms of the areal coverage of the spill, the volume of oil entrained within individual ice pieces in the ice field, and the volume of recoverable oil remaining, all as a function of time. These curves are based on the assumption that the areal coverage of the spill is relatively limited due to containment by the broken ice field until the ice concentration reaches the 75% point, after which further deterioration of the ice results in a relatively rapid increase in the spreading of the spilled oil to its limiting open water thickness. As oil-ice interaction continues and the ice deteriorates, the volume of oil entrained in the ice increases. The volume of recoverable oil available to the spill response operation declines as a result of evaporation into the atmosphere and dissolution into the water column.

Spill Response

As previously mentioned, the oil spill is assumed to be detected visually by the deck watch within 20 minutes after the initial release of oil. The casualty will be reported by ship's radio to the Coast Guard and to other appropriate authorities.

Initial surveillance will be accomplished by the crew of the damaged tanker. The tanker is assumed to be required to remain at the spill site until it is relieved by a relief tanker or by a Coast Guard icebreaker. While at the site, the tanker will undergo further inspection to evaluate the damage and to determine the action required to prevent any additional spillage of oil. If for safety reasons the tanker is forced to leave the spill site, the spill should be marked with buoys and a radio beacon so that it can be located by fixed-wing aircraft, helicopters, a relief tanker or an icebreaker. Because of the remoteness of the area, it is very unlikely that the spill could be relocated without such a marking system. After the ship's track has closed due to ice dynamics resulting in a contaminated field of pressure ridges, hummocks, and rafted ice, the preferred surveillance technique is for work crews working on the ice with hand-held ice augers or ice drills to determine the extent of the spill, and the location of the more highly concentrated pockets of oil. This work could begin only after an icebreaker transports the needed manpower and equipment to the spill site. It is assumed that it would take five days for an icebreaker to make the trip to the spill site from Kodiak. As was the case in the previous scenarios, the use of electronic remote sensing devices such as impulse radars, pulsed laser fluorometers, and microwave detectors may have some limited applicability, but their use in the ice conditions of this area have not been demonstrated. The preferred surveillance technique of work crews operating on the ice with hand-held augers has been estimated to require nine teams of four men working twelve hours per day for a three day period.

No apparatus currently exists for the effective containment of an oil spill in a moving field of vast ice floes, however, the oil is effectively contained by the broken ice field for at least a 30 day period. Since the transit time for an icebreaker to arrive from Kodiak is five days, the oil spill will be effectively contained by the ice cover for a long enough period

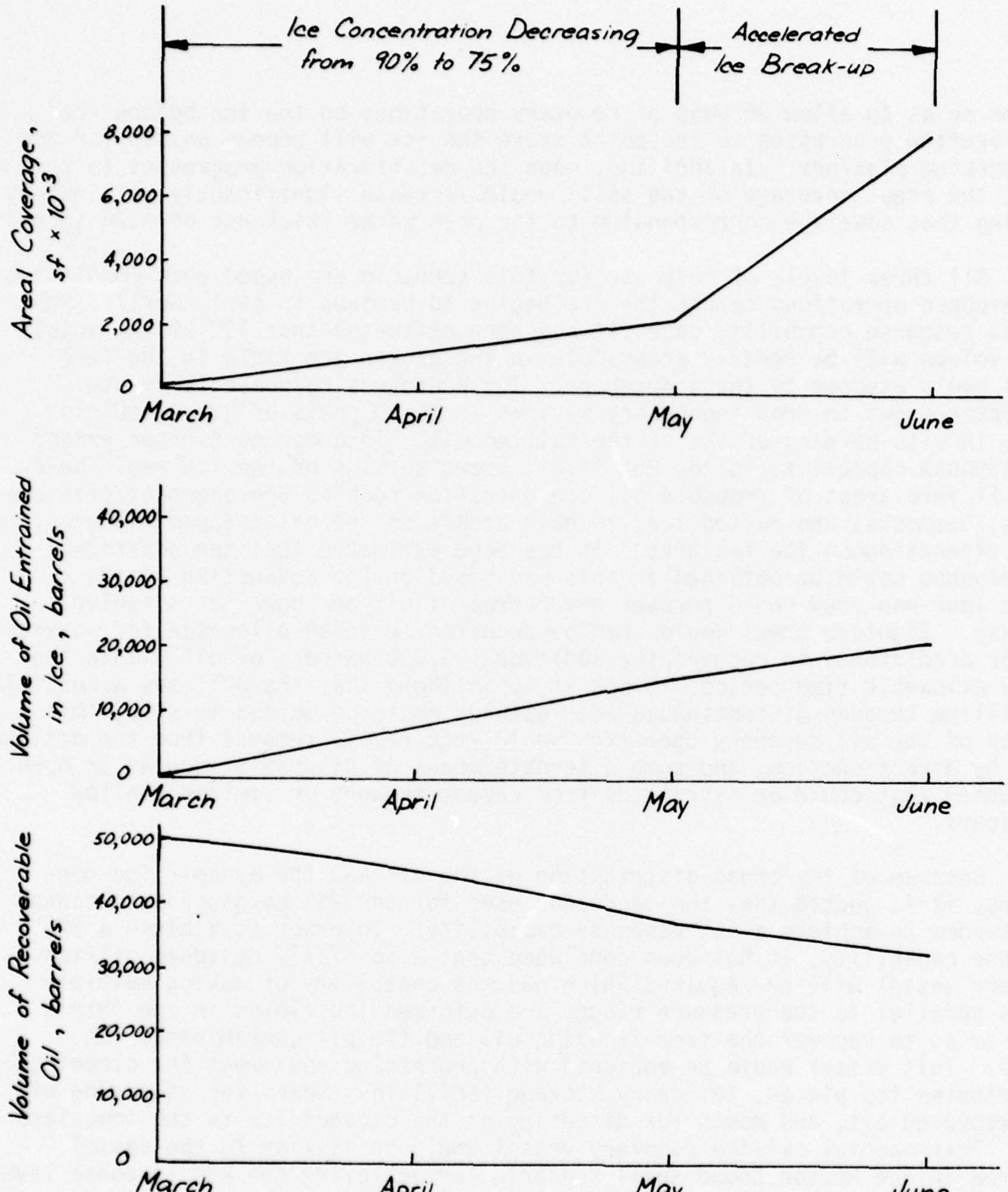


Figure 71. Summary of the Projected Behavior of Oil Spilled in the Navarin Basin Scenario in Terms of Areal Coverage, Volume of Oil Entrained in Ice, and the Volume of Recoverable Oil Remaining.

of time so as to allow 25 days of recovery operations on the ice before ice deterioration progresses to the point where the ice will become unsafe for use as a working platform. In addition, when ice deterioration progresses to this point, the areal coverage of the spill would increase significantly, ultimately reaching that coverage corresponding to the open water thickness of 0.28 inches.

All three levels of response for this scenario are based upon completing all response operations before the ice begins to breakup in early April. For the 25% response capability case, it has been estimated that 15% of the total spill volume will be readily accessible in the broken ice field in the form of oil pools exposed to the atmosphere. The preferred response is to use helicopter crews to drop incendiary devices in these pools of oil, resulting in the in situ burning of 15% of the spilled oil. In order to further extend the response capability to the 25% level, crews working on the ice would have to drill into areas of probable oil concentration such as the edges of pressure ridges, hummocks, and rafted ice, to gain access to the oil trapped along or in these discontinuous ice features. It has been estimated that the additional 10% response could be obtained in this way based on the assumption that a single four man crew could recover one barrel of oil per hour for a twelve hour day. Eighteen crews would then be required, with an allowance for adverse weather conditions, to recover the additional 5,000 barrels of oil within the 25 day allowable time period. Since it is unlikely that the oil made accessible by drilling through discontinuous ice features could be burned in situ, this portion of the oil recovery operation would require oil removal from the drilled holes by direct suction, and some alternate means of disposal, such as an open pit burner that could be fabricated from cement troughs or similar shallow containers.

Because of the broad distribution of the oil and the dynamic ice conditions, it is judged that the technique used for the 25% response case cannot be extended to achieve a 50% response capability. In order to achieve a 50% response capability, it has been concluded that a specially designed oil/ice recovery vessel will be required which has the capability of making multiple passes parallel to the pressure ridges and deformed ice fields in the ship's track so as to recover the free-floating oil and the oil contaminated ice pieces. This vessel would be equipped with processing equipment for cleaning contaminated ice pieces, temporary storage facilities, means for disposing of the recovered oil, and means for disposing of the cleaned ice in the immediate area. This special oil/ice recovery vessel would be similar to the vessel required in the Norton Sound spill scenario for achieving the 80% response level. The extension of the response capability for the Navarin Basin scenario from 50% to the 80% level then only requires the continued operation of this special oil/ice recovery vessel for some additional time period.

Temporary storage and transfer requirements are associated only with a portion of the 25% response level case for this scenario. For the 25% response, oil that was not burned in situ could be stored in small bladders and transported for intermediate storage to the icebreaker or the tanker. The temporary storage problem could also be bypassed by immediately pumping the oil to a

shallow vessel, such as a cement trough, in which the oil would be periodically ignited for onscene disposal. Barges with icebreaker support could also be used if they could be transported to the spill site quickly enough. The preferred response consists of the use of fireproof shallow containers for the disposal of the 10% of the oil which is physically recovered, thereby bypassing the temporary storage problem. Transfer could be accomplished by using pumps capable of pumping highly viscous oils, or by using vacuum systems for the direct suction portion of the 25% response technique. The special oil/ice recovery vessel is assumed to be equipped with all components necessary for the transfer, temporary storage, and concurrent disposal of oil which is being recovered by the device as described in the 80% response to the Norton Sound spill scenario.

Logistics are especially difficult for this scenario because of the remoteness of the location and the time constraints imposed by the approaching breakup of the ice field. Ice thicknesses are insufficient to support the landing of fixed-wing aircraft at the spill site which is 160 miles from St. Lawrence Island. Some helicopters may have the range to reach the spill site, and such helicopters could be used in the effort to burn the accessible 15% of the oil in situ. Extending the response capability beyond this initial 15% level requires the use of a marine vehicle as a staging site for operations, such as an icebreaker or a relief tanker. For the case of a Coast Guard icebreaker deployed from Kodiak, it is assumed that all response equipment and personnel can be taken on board at Dutch Harbor. The icebreaker would serve as the onscene command and communications center. The tanker will provide additional berthing and galley services for response personnel. The icebreaker's helicopter will be used for transferring personnel and supplies when necessary.

Ancillary functions of weather forecasting, ice forecasting and emergency evacuation will be independent of the level of the response effort. The use of an oil spill behavior model could be beneficial in this scenario for predicting the movement and spreading of the oil when ice breakup begins.

Because of the remoteness of the area and the ice conditions at this time of year, the paramedical facilities of the icebreaker will be the primary facilities for emergency medical care. Emergency cases could be transported from the spill site to St. Lawrence Island by long-range helicopter, and then to Fairbanks or Anchorage as needed for additional medical care. The icebreaker's helicopter should always be on call for evacuating personnel from the ice to the icebreaker.

Table 30 is a summary of the preferred spill response techniques for the Navarin Basin spill scenario for three levels of spill response capability. The equipment and labor associated with the preferred oil spill responses developed for this scenario are outlined in more detail in Tables 31, 32 and 33 for the 25, 50 and 80% levels respectively.

TABLE 30. SUMMARY OF PREFERRED SPILL RESPONSE TECHNIQUES FOR THE NAVARIN BASIN SPILL SCENARIO

Function	25% Response Level	50% Response Level	80% Response Level
Detection	Visual observation by ship's crew	Same	Same
Surveillance	Drill holes in the ice to determine the presence or absence of oil	Same	Same
Containment	Natural	Natural	Natural
Recovery	In situ burn exposed oil; drill to gain access to addition oil	Special oil/ice recovery vessel	Special oil/ice recovery vessel
Storage	Shallow pans like cement troughs	Special oil/ice recovery vessel	Special oil/ice recovery vessel
Transfer	Portable pumps	Special oil/ice recovery vessel	Special oil/ice recovery vessel
Disposal	15% burned in situ, 10% burned in open troughs	Speical oil/ice recovery vessel	Special oil/ice recovery vessel
Logistics	Icebreaker from Kodiak, personnel and supplies from Dutch Harbor, icebreaker as operations base	Icebreaker and special oil/ice recovery vessel	Same
Ancillary	Weather and ice forecasts, marking beacons, spill behavior prediction model	Same	Same
Emergency Evacuation	Icebreaker's helicopter and paramedical facilities, personnel emergency beacons	Same	Same

TABLE 31. EQUIPMENT AND LABOR ASSOCIATED WITH A 25% RESPONSE TO SCENARIO NO. 4 - NAVARIN BASIN

A. SURVEILLANCE (3 days on scene)

1 Operation Manager
9 Supervisors
27 Laborers
9 Hand Held Powered Augers, 6 in x 6 ft bits
9 Chain Saws, 6 ft blades
750 Disposable, Buoyant Surface Markers

<u>Logistics for Surveillance</u>

USCG Polar Icebreaker (5 days from Kodiak to Scene)
USCG Polar Icebreaker (On scene for 3 days)
Consumables for 3 days
Miscellaneous

B. CONTAINMENT

None

C. RECOVERY (In-situ burning - 3 days)

1 Operations Manager
1 Supervisor
2 Laborers
1,000 Incendiary Devices (Thermite, Phosphorus, or Kontax)

<u>Logistics for Recovery</u>

1 Helicopter

RECOVERY (25 days on scene and 10 days in transit)

1 Operations Manager
18 Supervisors
54 Laborers
18 Augers, 6 in x 6 ft bits
18 Chain Saws, 6 ft blades

<u>Logistics for Recovery</u>

USCG Polar Icebreaker (On scene for 25 days)
USCG Polar Icebreaker (Returning to port, 5 days)
Consumables by Crew While in Transit
Consumables by Crew While on Site
Setup and Breakdown of Equipment
Miscellaneous

TABLE 31. EQUIPMENT AND LABOR ASSOCIATED WITH A 25% RESPONSE TO SCENARIO NO. 4 - NAVARIN BASIN (Continued)

D. STORAGE

50 25 gal Cement Troughs

E. TRANSFER

18 Transfer Systems for High Viscosity Oil, 50 gpm of crude oil @ -5°F
18-100' Hoses

F. DISPOSAL

In-Situ Burning

G. ANCILLARY

Communications Equipment

H. EMERGENCY EVACUATION

73 Individual Emergency Beacons

TABLE 32. EQUIPMENT AND LABOR ASSOCIATED WITH A 50% RESPONSE TO SCENARIO NO. 4 - NAVARIN BASIN

A. SURVEILLANCE

Same as 25% Response

B. CONTAINMENT

None

C. RECOVERY (15 days on scene, 10 days in transit, 5 days breakdown)

25% Response List
2 Operational Managers
4 Supervisors
10 Laborers
Oil/Ice Recovery Vessel

Logistics for Recovery

USCG Polar Icebreaker (10 days transit, 15 days on scene)
2 Invader Class Tugs
Miscellaneous
Consumables by Crew

D. STORAGE

Part of Oil/Ice Recovery Vessel

E. TRANSFER

Part of Oil/Ice Recovery Vessel

F. DISPOSAL

Part of Oil/Ice Recovery Vessel

G. ANCILLARY

Communications Equipment

H. EMERGENCY EVACUATION

None

TABLE 33. EQUIPMENT AND LABOR ASSOCIATED WITH AN 80% RESPONSE TO SCENARIO NO. 4 - NAVARIN BASIN

A. SURVEILLANCE

Same as 25% Response

B. CONTAINMENT

None

C. RECOVERY (25 days on scene, 10 days in transit, 5 days breakdown)

25% Response List
2 Operations Managers
4 Supervisors
10 Laborers
Oil/Ice Recovery Vessel

<u>Logistics for Recovery</u>

USCG Polar Icebreaker (10 days transit, 25 days on scene)
2 Invader Class Tugs
Miscellaneous
Consumables by Crew

D. STORAGE

Part of Oil/Ice Recovery Vessel

E. TRANSFER

Part of Oil/Ice Recovery Vessel

F. DISPOSAL

Part of Oil/Ice Recovery Vessel

G. ANCILLARY

Communications Equipment

H. EMERGENCY EVACUATION

None

Scenario 5 - Bristol Bay

Spill Mode

The oil spill situation selected for the Bristol Bay scenario consists of an oil well blowout from an average size reservoir during exploratory drilling operations eminating from a ground fault at a rate of 5,000 barrels per day of oil accompanied by 750 scf of gas per barrel of oil. This release occurs in December when Bristol Bay ice conditions are characterized by 1 ft thick growing, hummocky, and moving ice. It is assumed that the blowout will be arrested by the completion of a relief well after a period of 45 days, resulting in a release of a total of 225,000 barrels of oil.

Environmental Conditions

Bristol Bay is characterized as two zones, an outer bay which is roughly 58,000 square miles in area, and an inner bay which is about 10,000 square miles in area. The spill site selected for this scenario is near the center of the inner bay. The inner bay region is completely dominated by estuarian phenomena, while the outer bay has more of an ocean character. In the inner bay, particularly in the mouths of the rivers, significant local tidal currents are observed, and as in many esturarian areas, some of the ebb tidal currents considerably exceed the flood currents due to the influence of river flow. The most severe ice conditions occur in the inner bay in February and March when there may be many scattered regions of shorefast ice, however, the considerable tidal amplitudes still tend to keep the ice in the inner bay broken up. At the time of the blowout the thickness of the ice cover in Bristol Bay is expected to be about 1 ft. The ice will be in a growing condition and the concentration of the ice field will be about 50%. Ice growth continues through the month of January, reaching a mean thickness of 2 ft, with the concentration of the ice field increasing to 70%. The thickness of the ice will continue to increase in February, reaching a mean thickness of 2-1/2 ft, with the concentration of the ice field increasing to 75%.

Mean air temperatures at the blowout site are typically 12°F in December, 13°F in January, and 17°F in February. Typical water temperatures in Bristol Bay range between 32°F and 35°F during the months of December, January and February. The water depths in the area are 12 fathoms, well in excess of any requirements for spill response vessels. Tidal currents in the Bristol Bay area are second in the state of Alaska only to Cook Inlet tidal currents, reaching maximum surface velocities of 1.3 knots. Bristol Bay also has the second greatest tidal range in the State of Alaska, with the tidal range extending up to 18 ft at the very end of Bristol Bay, and taken as 16 ft at the spill site.

Bristol Bay experiences relatively short periods of sunlight during the winter months, with 6 hours of daily sunlight typical for December, 7 to 8 hours for January, and 9 to 10 hours for February. Obstructions to vision, defined as conditions that reduce visibility to 6 miles or less, can be expected in Bristol Bay 10% of the time in December, 9% of the time in January, and 7% of

of the time in February. The monthly average snowfall is 4 inches in December, 6 inches in January, and 7 inches in February.

Mean wind velocities in Bristol Bay can be expected to be 16 mph in December, 18 mph in January, and 14 mph in February, all from an east-northeasterly direction. In spite of the significant winds, wave heights in excess of 5 ft are improbable at this time of the year due to the presence of the ice cover. This area experiences an average of 1.2 storms per month for each of the months of December, January, and February. Bristol Bay is in a zone of high seismic activity, and it has been classified as an area where there is a major possibility of substantial damage occurring to structures due to earthquakes. The area directly south of Bristol Bay, to the south of the Aleutian Island chain, is one of the most active earthquake areas in the world.

Spill Behavior

Oil released from the oil well blowout with its accompanying gas is expected to become thoroughly mixed with the ice cover due to the very dynamic ice conditions in the area. Since ice concentrations are never expected to exceed 75% during the three month period following the blowout, the gas eminating from the blowout will be vented to the atmosphere. The oil will also tend to flow to the open water leads in the ice field, however it is possible that some degree of thickening of the oil slick will occur due to partial containability by the ice field. This thickening of the oil slick has been approximated as a thickness of 0.5 inches in comparison to the typical open water terminal thickness of 0.28 inches. The net movement of the oil and the ice field is projected to be out of the bay at a rate of approximately 10 miles per day in a west-southwesterly direction. This net movement is primarily governed by the winds.

The ice typically grows another foot during the month of January, and the ice concentration increases to 70%. In areas where oil is present during major periods of ice interaction, the oil will become intermixed within the ice field and will be transported with the ice field. Ice floes interacting in the presence of oil will be coated with the oil. The penetration of oil into the ice pieces is projected to typically be 2 inches in depth reaching concentrations up to 5% oil by volume. By the end of February it is projected that 50% of the oil released will be entrained in the ice field. Free-floating oil would either be transported into the outer bay where it would further interact with the ice floes, or would concentrate along the edges of the shorefast ice. Weathering rates will vary greatly depending upon the interaction of the oil with ice and snow. Typically, oil beneath the ice will lose 6% of its volume by weathering, snow covered oil will lose 12% of its volume by weathering, and oil exposed to the atmosphere will experience losses ranging from 25% to 33% of its volume within a period of 2 weeks. As ice growth continues, the oil which has penetrated the ice field will be incorporated into the ice in a more stable form until ice breakup occurs.

Figure 72 summarizes the estimated behavior of the spilled oil in the Bristol Bay scenario in terms of the areal coverage of the oil spill, the volume of oil entrained in the ice, and the volume of recoverable oil remaining for the spill response effort. The initial increase in the areal coverage of the spill is related to the continuing blowout itself, while the increase in areal coverage after the first 45 day period is primarily related to the continued spreading of the oil slick from its condition of partial containment within the ice field to its ultimate open water thickness. In a similar manner, the first period of increase in the volume of oil entrained in the ice is primarily related to the continuing blowout, after which time the entrainment of oil within the ice tapers off to a limiting condition about 3 weeks after the blowout is arrested. The volume of oil recoverable increases throughout the blowout period with an allowance made for weathering losses, after which the weathering losses continue such that by the end of February only about 175,000 barrels of the total spillage of 225,000 barrels remains available for possible recovery.

Spill Response

Problems at the exploratory well drill site will first be detected by operating personnel from readings of abnormal well pressures. The blowout itself will be detected visually when the oil and gas rise to the surface in the neighborhood of the drill rig. The incident will be reported to the appropriate authorities through normal channels of communication.

Surveillance of the spilled oil for the Bristol Bay scenario must be performed through overflights using fixed-wing aircraft and helicopters. Visual detection will be limited to the 25% response level case due to the limited amount of daily sunlight. For the 25% response level, two overflights per day with a fixed-wing aircraft should be adequate using visual observation to map the movement of the spilled oil. Electronic devices capable of observing the spill during the extended periods of darkness will be necessary to increase the response level to 50%. No such devices have been demonstrated to date for detecting oil within broken ice fields; however, some methods appear to offer some limited degree of capability. It has been estimated that four overflights per day with fixed wing aircraft equipped with special remote oil sensing equipment would be required for this level of response. The 80% response level would require that the periods of successful surveillance be further extended to include other conditions in which further obstructions to vision occur, such as fog and blowing snow. Again, no devices have yet been demonstrated for application under these conditions, and an R&D program would be required. Conceptually, thermal infrared detectors, microwave detectors, and pulsed laser fluorometers appear to have some promise for limited applicability, but none have been tested for use under these conditions. Because of the dynamic conditions of the spilled oil in the ice field, and the continuous release of oil from the blowout, it has been estimated that the 80% response level would require that the spill be monitored at four-hour intervals. Six overflights per day would therefore be required by fixed-wing aircraft, equipped with an array of electronic detection devices capable of monitoring the location of the oil in moving fields of broken ice cover.

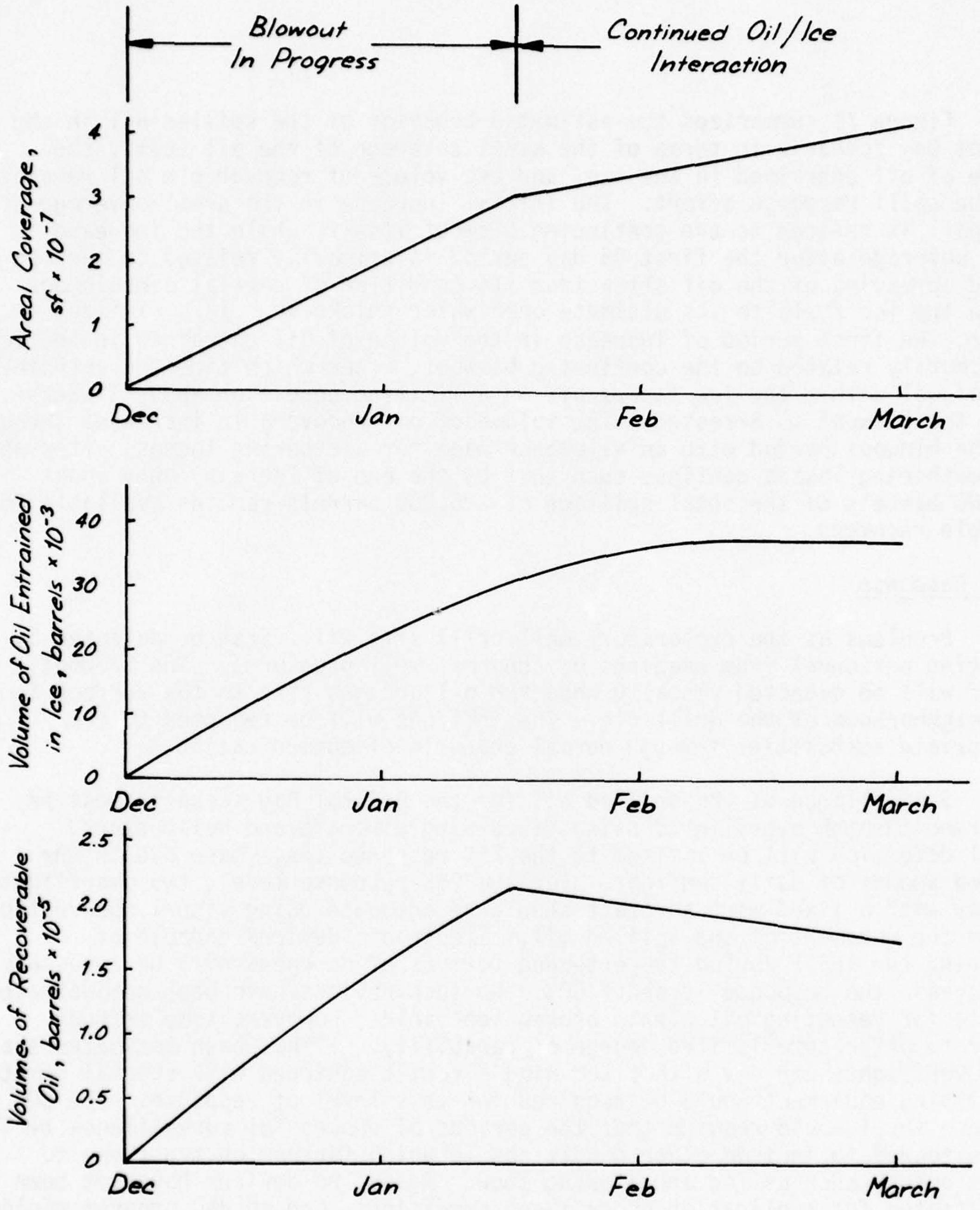


Figure 72. Summary of the Projected Behavior of Oil Spilled in the Bristol Bay Scenario in Terms of Areal Coverage, Volume of Oil Entrained in the Ice, and the Volume of Recoverable Oil Remaining.

Conventional oil containment booms would be totally inadequate for application in the environmental conditions of this area which include tidal variations of 16 ft, currents of up to 1.3 knots, dynamic ice fields of 50 to 75% concentration drifting in various directions and at various velocities depending upon local wind and current effects, and ice floe sizes of up to 2,000 ft across. Containment techniques which have been suggested for use in regions having environmental conditions similar to those expected for Bristol Bay include the use of a dome or similar type of submerged containment system which would be installed on the sea floor over the blowout, and the use of a containment net which would be used to concentrate oil flowing from the blowout for in situ burning over the blowout site. The combined use of oil containment booms with ice booms is another possibility. For example, an ice boom could be installed to deflect the moving ice floes away from an oil containment boom, which would channel the spilled oil to an open water recovery device. Another possibility considered was the use of ice booms to maintain an area of stable ice cover at the blowout site, which would in turn act as a containment vessel for the spilled oil. The approach identified as the most practical in the near term future, and therefore selected as the preferred containment response, consists of the localized application of conventional containment booms in conjunction with ice management operations, rather than the general application of containment booms in the conventional sense. Oil will trail in various directions from the blowout site due to tidal currents and wind drift, with a net movement out of Bristol Bay. The width of the track will typically be about 10 ft, being somewhat broader in regions of slack water and narrower in regions of high currents. By using ice management techniques in conjunction with sweeping, conventional containment booms could be deployed in a sweeping configuration between tugs with an oil spill recovery device located in the bight of the boom between the tugs. The conventional containment booms are therefore used to help concentrate the oil streaming from the blowout for recovery rather than for containment itself. Clearly, only the most rugged of the conventional containment booms could be considered for use, since small ice pieces will be present even in the relatively open water regions. A demonstration program would be required in the type of ice conditions expected in order to verify the applicability of this technique. The use of this technique is shown conceptually in Figure 73, which shows the use of conventional heavy duty containment booms for gathering spilled oil while tugs are used to escort large ice floes away from the sweeping operation.

Because of the dynamic conditions associated with this oil spill scenario including the effects of winds, currents, tides, and ice dynamics, in situ burning was judged to be an inappropriate response for this scenario. Passing ice floes could repeatedly extinguish the flame, floating patches of burning oil could present a safety hazard to marine operations and the operations concerned with drilling the relief well, and the volume of oil released may be capable of being handled in a more desirable way which would not result in the heavy smoke usually associated with in situ burning. For the 25% response level, the technique described in the preceding paragraph and shown schematically in Figure 73 is preferred. The mechanical oil spill recovery device operating in the bight of the sweeping boom could be any one of several devices which are currently in development or currently available

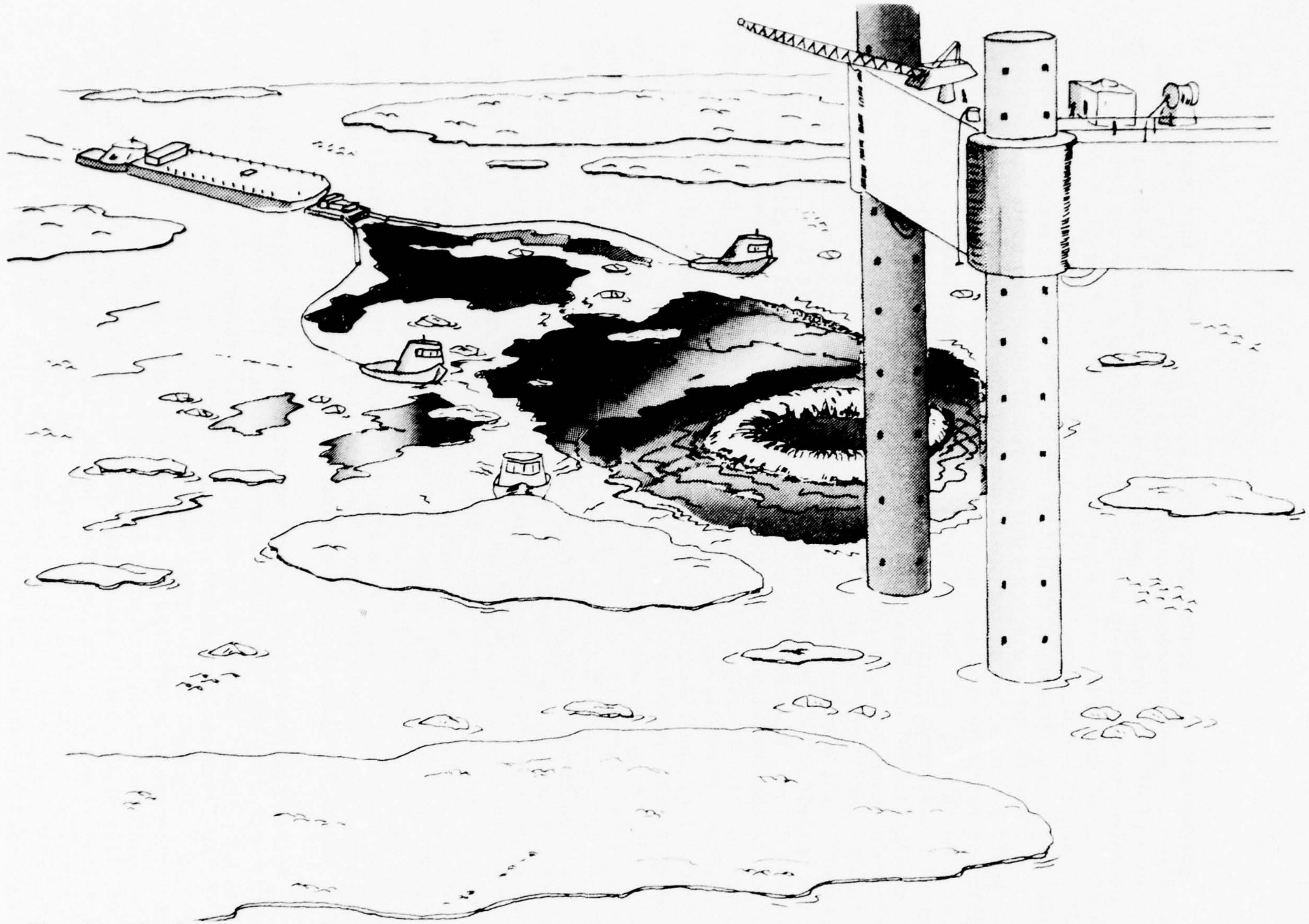


Figure 73. Schematic Representation of the Ice Management - Sweeping Recovery Technique Developed to Provide a 25% Response Level for the Bristol Bay Scenario.

including the Lockheed Clean Sweep Arctic Boat, the Oil Mop Dynamic Skimmer, and the U.S. Coast Guard's Zero Relative Velocity (ZRV) Oil Spill Recovery Device. The type of mechanical recovery device employed must be capable of processing or passing over small ice pieces so that the suction area of the recovery device does not become clogged with ice, which would subsequently prevent the passage of oil to the recovery device. The Lockheed Clean Sweep Unit has this ice processing feature inherently in its design, and the Oil Mop Dynamic Skimmer and the ZRV recovery device would likely operate over the surface of broken ice pieces of moderate size without significantly hindering the oil spill recovery process. Other conventional oil spill recovery devices could also be used if they were modified for ice processing. The oil spill recovery devices for the 25% response level would be deployed in the bight of the boom, which would be used in a manner so as to present the oil spill recovery device with a relatively concentrated supply of oil. An additional tug would be required ahead of the tug/sweeping boom/oil recovery device system for diverting large ice floes away from the recovery system. Another tug and a storage barge operating just aft of the recovery device completes the system by providing propulsion for the recovery device and by providing the necessary temporary storage capacity. In order to recover 25% of the spilled oil, the recovery device would have to recover 36 gpm over a 24 hour period. Special lighting must be provided to support 24 hour per day operations.

It is judged that the response level could be increased to 50% by extending the 25% response level technique to include two sets of recovery systems. In addition, it has also been judged that it would be necessary to have crews search out and recover oil from any concentrated areas, such as areas of shorefast ice where winds and local currents may have deposited relatively concentrated pools of oil. Mechanical recovery devices and adsorbent materials could be used to recover a substantial quantity of this oil. The procedure envisioned is to use a small work boat with a portable skimming device with bladders or oil drums on board for temporarily storing the oil.

Further extension of the response capability to 80% goes beyond the capability judged possible from the use of this technique, and is judged to require the use of a specialized oil/ice recovery vessel having the capability of processing large ice floes up to one foot in thickness traveling at speeds of up to 2 knots. Such a device, shown previously in Figure 70, does not exist at the present time and requires development. In addition to the use of this special vessel, one recovery team would be required to recover oil which has escaped the special oil/ice recovery vessel. The requirements for this recovery team would be identical to the teams used for the 25 and 50% response levels. The team would have to operate continuously for the 45 day period of the blowout. Two crews of men would be required to clean oil along the shorefast ice using mechanical recovery units and adsorbent materials. The shorefast ice would serve to protect the shoreline from contamination by oil. Any shoreline cleanup activities required following the melting of the shorefast ice are beyond the scope of this study and are therefore not included.

Temporary storage for all three levels of response will be provided by a barge towed behind the oil spill recovery device. The recovery crews removing oil from concentrated pools along the shorefast ice and other areas will require either open top containers or collapsible storage bags which can be

used on the work boat. A small barge could also be used with this operation. For the primary response vehicle for the 80% level, the oil/ice recovery vessel, it is assumed that the necessary temporary storage capacity is designed within the unit.

Transfer of the recovered oil from the oil spill recovery devices to the temporary storage systems will require pumps capable of handling a slurry of highly viscous oil and small ice pieces. Since the oil is assumed to have a pour point of -5°F and average air temperatures will be around 12°F in December, no requirements for specialized pumping systems incorporating heat are anticipated. Conventional centrifugal or positive displacement pumps having the capability to pass small solids should be adequate.

While it may be possible to re-inject the recovered oil into the well, or transport it to a refinery for dewatering and refining, it is conservatively assumed in this scenario that the oil is disposed of on location through the use of open flame burners. An alternative disposal mechanism is the use of open pit burners which could be barge mounted; however, the efficiency of disposal and the rate of disposal would typically not be as high with open pit burners as could be obtained through use of oil field type open flame burners.

Since oil recovery operations will be marine vessel based, the logistics effort must be compatible with these operations. Equipment and supplies can be staged from a number of nearby airports and transported by roads to local port facilities where they can be transferred by marine vessels to the spill site. Equipment and personnel can also be flown to the site by helicopter. For the 25% response level, the tugs and barges should be available within a one to two day travel distance from the spill site. For the additional response capability required to achieve the 50% level, vessels will likely have to come from as far away as Anchorage. Berthing and support facilities will be based at a nearby port such as Port Heiden.

In addition to the usual ice and weather forecasting functions, an additional ancillary function includes the use of an oil spill trajectory model which could be particularly useful in this scenario due to the very dynamic nature of the spill situation. Based on current weather and oceanographic information, the spill trajectory model could be very valuable in planning the spill response effort. Normal communications channels would be available for emergency situations. A helicopter will be dedicated to the emergency evacuation function. Emergency cases could be flown by the helicopter to hospital facilities in Anchorage in a short period of time.

The preferred spill response techniques for the Bristol Bay oil spill scenario are summarized for the three response levels in Table 34. A more detailed outline of the equipment and labor associated with the preferred oil spill responses developed for this scenario are summarized in Tables 35, 36 and 37, respectively, for the 25, 50, and 80% response levels.

TABLE 34. SUMMARY OF PREFERRED SPILL RESPONSE TECHNIQUES FOR THE BRISTOL BAY SPILL SCENARIO

Function	25% Response Level	50 Response Level	80% Response Level
Detection	Abnormal well pressure readings and visual observation of blowout	Same	Same
Surveillance	Visual observation from aircraft during daylight and good weather	Same plus remote electronic devices to extend operations into periods of darkness	Same plus remote electronic devices to extend operations into periods having obstructions to vision
Containment	Sweeping with conventional heavy duty containment booms in open water regions	Same, but two systems	Same
Recovery	Conventional open water devices having ice processing capability inherent or added	Same, but two systems	Same plus special oil/ice recovery vessel plus shore-fast ice edge recovery system
Storage	Barge	Barges	Same plus onboard storage of special vessel plus open top containers for ice edge recovery
Transfer	Conventional pumps having some solids passing capability	Same	Same
Disposal	Open flame burner	Same	Same plus disposal system of the special vessel
Logistics	Port Heiden as staging area for marine operations	Same	Same
Ancillary	Weather, current and ice forecasts, spill behavior prediction model	Same	Same
Emergency Evacuation	Dedicated helicopter, personnel emergency beacons	Same	Same

TABLE 35. EQUIPMENT AND LABOR ASSOCIATED WITH A 25% RESPONSE TO SCENARIO NO. 5 - BRISTOL BAY

A. SURVEILLANCE (55 days, 2 overflights per day)

1 Operations Manager
1 Supervisor
2 Laborers
100 Buoyant Disposable Surface Markers (Orion or equal)

Logistics for Surveillance

1 Cessna 402

B. CONTAINMENT

600 ft High Seas Containment Boom

C. RECOVERY (45 days operation, 10 days setup and breakdown)

2 Operation Managers
2 Supervisors
8 Equipment Operators
6 Laborers
1 Arctic Boat Oil Recovery Device

Logistics for Recovery

2 100 ft. Tugs
1 Daring Class Tug
1 Invader Class Tug
Fuel for Marine Vessels
4 1,000 w Lighting Systems
2 7.5 kva Generators (500 lb each)
8 50,000 BTU Heaters
Miscellaneous
Consumables

D. STORAGE

1 10,000 bbl Tank Barge

E. TRANSFER

2 Self-Priming Portable Pumps for 200 gpm @ 150 ft discharge

F. DISPOSAL

1 Open Flame Burner System for 125 bbl/hr (6,000 lb)

TABLE 35. EQUIPMENT AND LABOR ASSOCIATED WITH A 25% RESPONSE TO SCENARIO NO. 5 - BRISTOL BAY (Continued)

G. ANCILLARY

Communications Equipment

H. EMERGENCY EVACUATION

None

TABLE 36. EQUIPMENT AND LABOR ASSOCIATED WITH A 50% RESPONSE TO SCENARIO NO. 5 - BRISTOL BAY

A. SURVEILLANCE (55 days, 4 overflights per day)

1 Operations Manager
1 Supervisor
2 Laborers
Special Electronic Remote Sensor
100 Buoyant Disposable Surface Markers (Orion or equal)

B. CONTAINMENT

25% Response Doubled

C. RECOVERY (For 55 days, workboat to intercept oil along shore)

1 Supervisor
1 Equipment Operator
4 Laborers
2 Skimmers, Clean Sweep or equal (14,000 lb each)
Adsorbent Material

<u>Logistics Recovery</u>

1 Work Boat
Consumables for Personnel
25% Recovery Doubled

D. STORAGE

2 500 Gallon Bladder Tanks (100 lb each)
20 Waste Drums
25% Storage Response Doubled

E. TRANSFER

2 Portable Pumps
25% Response Doubled

F. DISPOSAL

25% Response Doubled

G. ANCILLARY

Communications Equipment

H. EMERGENCY EVACUATION

None

TABLE 37. EQUIPMENT AND LABOR ASSOCIATED WITH AN 80% RESPONSE TO SCENARIO NO. 5 - BRISTOL BAY

A. SURVEILLANCE (total 55 days, 6 overflights per day)

1 Operations Manager
1 Supervisor
2 Laborers
1 Special Electronic Remote Sensor
100 Buoyant Disposable Surface Markers (Orion or equal)

<u>Logistics for Surveillance</u>

Cessna 402

B. CONTAINMENT

Same as 25% Response

C. RECOVERY (for 55 days)

2 Operational Managers
4 Supervisors
10 Laborers
Special Oil/Ice Recovery Vessel

<u>Logistics for Recovery</u>

2 Invader Class Tugs
Consumables by Personnel
25% Response List
50% Work Boat Response Along Shorefast Ice Doubled

D. STORAGE

25% Response List and 50% Shorefast Ice Cleanup Doubled
Storage as Part of Oil/Ice Recovery Vessel

E. TRANSFER

25% Response List and 50% Shorefast Ice Cleanup Doubled
Storage as Part of Oil/Ice Recovery Vessel

F. DISPOSAL

25% Response List
Disposal as Part of Oil/Ice Recovery Vessel

TABLE 37. EQUIPMENT AND LABOR ASSOCIATED WITH AN 80% RESPONSE TO SCENARIO NO. 5 - BRISTOL BAY (Continued)

G. ANCILLARY

Communications Equipment

H. EMERGENCY EVACUATION

None

Scenario 6 - Unimak Pass

Spill Mode

The oil spill situation selected for Unimak Pass consists of a collision in the center of Unimak Pass between a barge carrying arctic diesel fuel and another vessel. The collision results in the rupture of four cargo holds of the barge and the release of 10,000 barrels of arctic diesel fuel. This casualty is selected to occur in June when there is no ice present in Unimak Pass and mean air temperatures are in the range of 45°F.

Environmental Conditions

The Unimak Pass oil spill scenario was selected as the only open water scenario to be considered in this study. Typical air temperatures at Unimak Pass are 45°F in June, increasing to 50°F in July, and 51°F in August. The average water temperature over this period is typically 50°F.

Water depths in the area of the spill exceed 12 fathoms, and currents traveling northward through Unimak Pass range from 0.1 to 0.5 knots. The tidal range in this area is about 4 ft. About 16 hours of continuous sunlight per day can be expected in the month of June, increasing to 17 hours in July, and decreasing back to 16 hours in August. Vision is obstructed to 6 miles or less in the region by rain, sleet and fog about 18% of the time in June, 28% of the time in July, and 32% of the time in August. There are only traces of snow in the area in June, and expectations are for no snow in July and August. The percentage frequency of rain is 34% in June, 36% in July, and 40% in August.

Typical wind velocities are 16 mph from the west-northwest in June, 16 mph from the south-southeast in July, and 17 mph from the south-southeast in August. Waves in excess of 5 ft occur 5 to 10% of the time throughout the summer months. Waves greater than 8 ft in height occur 2 to 5% of the time, with waves greater than 12 ft occurring only 2% of the time during the summer months. One to two storms per month can be expected throughout the months of June, July, and August. The earthquake hazard is substantial in this area since the Aleutian Trench is one of the most active fault zones in the world. The likelihood of damage to structures in this area due to earthquakes has been judged to be extremely high.

Spill Behavior

The specific site selected for the Unimak Pass spill was a point in the middle of the pass as shown in Figure 74. The oil leaking from the barge will spread very rapidly on the surface of the water. To get some feeling for the rate of spreading and the areal coverage, the use of the Fay-Hoult spreading model results in a prediction that the areal coverage of the spill would be about 8.5×10^7 sf, with a thickness of 0.008 inches, in a period of approximately 17 hours. This calculation is based on no effect due to winds, waves and currents. In actuality, the slick thickness will probably become much thinner as time passes, reaching 1.5×10^{-6} inches in thickness before it becomes invisible to the naked eye.

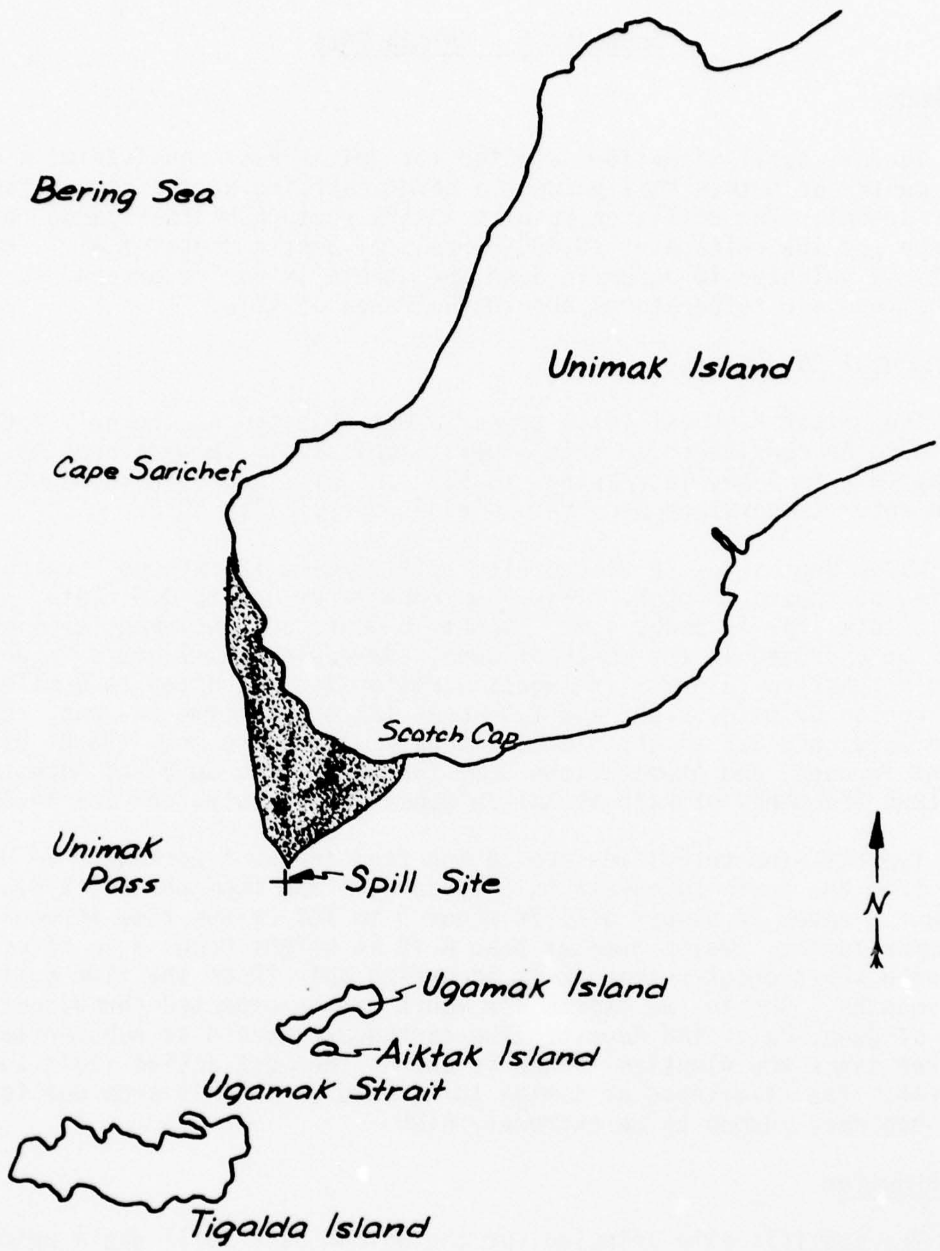


Figure 74. Location of Unimak Pass Spill and the Initial Coverage of the Spill.

Superimposing the effects of the wind at 16 mph from the west-northwest and the average current velocity of 0.3 knots in the northerly direction, the resultant slick transport would be at a rate of 0.6 knots in a north-north-easterly direction. The slick would therefore travel in a generally northerly direction through the pass to the southern shoreline of Unimak Island. It has been projected that the spill would reach the shore approximately 10 hours after the casualty occurs. Further projection of spill movement results in an impact on the north shore of the island within 72 hours of the time of the accident. Due to the rapid spreading of the oil and the high winds, a substantial volume of the oil spilled will be lost to evaporation within a relatively short period of time. It has been estimated that the entire 10,000 barrels spilled would completely evaporate within a 10 day period. A more detailed description of spill behavior in terms of areal coverage and the volume of recoverable oil remaining as a function of time would be extremely speculative. In the case of the areal coverage, one data point can be obtained through the use of the Fay-Hoult spreading model, however, the ultimate areal coverage could be substantially greater due to the continued spreading of the slick to the monomolecular thickness of the oil, and the breakup and further distribution of discrete patches of the oil due to winds, currents, and wave action. In the case of the volume of recoverable oil remaining, a curve could be generated on the basis of two data points of 10,000 barrels at time 0, and 0 barrels after a period of ten days, however, the shape of the curve, or the functional relationship with time, is undefined.

Spill Response

The spill of arctic diesel fuel from the barge will be detected by the crew of the tug at the time of the accident, and will be communicated to the Coast Guard and to shore facilities by ship's radio.

Initial on-site surveillance will be provided by the crew of the tug which was towing the barge. Subsequent surveillance will be provided by light aircraft until marine vessels arrive at the spill site. Airborne electronic surveillance techniques would be useful in mapping the extent of the spill and in locating areas of high oil concentration. Use of the Coast Guard's multiple surveillance techniques system, the Airborne Oil Surveillance System (AOSS), would be very valuable. Spill surveillance operations should be underway at the earliest possible opportunity due to the anticipated rapid spreading of the oil on the open water and the potential shoreline impact of the spill.

The very rapid spreading of the spilled oil will make any type of complete containment impractical. The only practical use of conventional oil spill containment booms could be in deployment along potentially affected shoreline regions for protection of the shoreline. Coves and ecologically sensitive inlets could be protected from oil contamination in this manner. Heavy duty conventional containment booms could also be used in a sweeping mode to aid in concentrating the spilled oil for recovery. While this study does include the use of booms for shoreline protection, it does not address the problem of shoreline cleanup. The spill response scenarios therefore do not include the equipment, manpower and costs associated with any requirements for shoreline cleanup.

For this scenario, the level of spill response capability is primarily

determined by the response time, the very rapid spreading of the spilled oil, and the rapid evaporation of the oil. It is projected that at least 20% of the oil will evaporate into the atmosphere within 10 hours of the spill. Based on a consideration of these factors it has been judged that the maximum response capability possible for this scenario is the 25% response. The preferred response consists of the use of conventional oil containment booms in a sweeping mode in conjuction with open water recovery devices situated at the bight of the boom. In order to achieve the 25% response capability, it has been judged that four oil spill recovery teams will be required to work around the clock for a 48 hour period. Each oil spill recovery team will consist of two tugs employing conventional containment booms in a sweeping mode with a conventional open water recovery device operating in the bight of the boom, and a barge located near the recovery device for temporary storage of the recovered oil. It is recognized that it may be difficult to assemble the response team within the required seven hours at this time of year, since in June most marine equipment in the area is in use. Detailed plans may have to be developed and commitments obtained from equipment owners and operators to provide the required response capability as outlined in this spill response scenario. In addition, a barge, tug and high speed pumping system, such as the ADAPTS, would be required to offload the stricken barge.

Temporary storage requirements for the recovered oil can be met through the use of nearby barges and towable, air deployable storage bags. One barge or storage bag should be adequate for use with each of the four response teams.

Because of the relatively low viscosity of the arctic diesel fuel and the fact that there are no traces of ice present in the area, conventional pumping systems can be used for transferring the recovered oil from the spill recovery device to temporary storage, and from temporary storage to disposal.

While it is possible that the recovered oil/water mixture could be disposed of through the use of open flame burners located on the barges, the preferred method consists of transporting the recovered oil to land based oily waste treatment plants.

The logistic functions will be critical to this scenario due to the rapid spreading of the oil. Two staging alternatives are available to meet the time requirements. Sweeping booms and recovery devices which are air deployable could be dropped to local vessels waiting at the recovery site, or equipment could be transported by air to a nearby airport and then on land to a nearby harbor. If these alternatives are not practical, the recovery equipment would have to be permanently stored in a ready condition at a nearby location, such as Dutch Harbor. Coast Guard vessels could arrive in three days from Kodiak to witness the final stages of any shoreline cleanup operation. The response must be built around available local vessels since marine vehicles having to transit any significant distance will arrive on scene too late to participate in the response operation. The probability of having the desired eight tugs and five barges available in a ready condition to respond to the spill is very low unless prior arrangements have been made. This is especially true during the summer months when most fishing vessels, tugs, and barges are experiencing their peak utilization. If prior arrangements are not made, it is judged more probable that something on the order of four tugs and two barges

could be made available on short notice, which would provide the capability for recovering only about 6% of the spilled oil. The 25% response level therefore requires careful advanced planning in order to have the required equipment available on very short notice. Shelter and food for the response teams will be provided by the recovery vessels and supplemented by the nearby communities. Normal communications channels will be used between vessels and communications centers in Dutch Harbor and Unimak Island.

Since the recovery operation must be directed to the areas of maximum oil concentration, and must recognize the need to protect especially ecologically sensitive areas, the use of an oil spill behavior model for predicting spill movement on the basis of weather and oceanographic data and forecasts would be useful. Extreme weather conditions would likely result in the total preclusion of successful recovery operations. Emergency medical procedures will consist of the immediate evacuation of personnel to Dutch Harbor, Unimak Island, or other nearby local hospitals by marine vessel or helicopter. If necessary, further transportation could be provided to major medical centers by fixed-wing aircraft.

The preferred technique for responding to the Unimak Pass spill of arctic diesel fuel is summarized in Table 38. The equipment and labor content associated with the preferred oil spill response for this scenario is outlined in more detail in Table 39. A 25% response level is judged to be the maximum response level achievable for this scenario.

TABLE 38. SUMMARY OF PREFERRED SPILL RESPONSE TECHNIQUES FOR THE UNIMAK PASS SPILL SCENARIO

Function	25% Response Level	50% Response Level	80% Response Level
Detection	Visual at time of collision		
Surveillance	Visual from tug and from fixed wing aircraft		
Containment	Booms for shoreline protection and for sweeping related to recovery		
Recovery	Conventional open water devices in a sweeping mode		
Storage	Barges and air *deployable* bladders		
Transfer	Conventional centrifugal pumps; ADAPTS for offloading barge	25% RESPONSE IS JUDGED THE MAXIMUM ACHIEVABLE	
Disposal	Shore-side oily waste treatment plant		
Logistics	Local marine vessels, air deliverable spill response equipment		
Ancillary	Weather and current forecasts; spill behavior prediction model		
Emergency Evacuation	Helicopter to Dutch Harbor, fixed wing aircraft to Anchorage		

TABLE 39. EQUIPMENT AND LABOR ASSOCIATED WITH A 25% RESPONSE TO SCENARIO NO. 6 - UNIMAK PASS

A. SURVEILLANCE (6 overflights for 4 days, 2 overflights for 6 days)

1 Operations Manager
1 Supervisor
2 Laborers
Electronic Remote Sensing

<u>Logistics for Surveillance</u>

Cessna 402

B. CONTAINMENT

2400 ft. of High Seas Containment Boom (3,000 lb)

C. RECOVERY (2 days on-scene, 2 days logistics, 2 days breakdown)

16 Operation Managers
16 Equipment Operators
8 Laborers
4 Clean Sweep Skimmers (14,000 lb each)

<u>Logistics for Recovery</u>

12 Tugs - Daring Class
4 Power Packs
Consumables by Personnel
Logistics to Fly All Equipment to Site

D. STORAGE

4 Barges

E. TRANSFER

4 Self-Priming Portable Pumps, 200 gpm @ 150 ft discharge
ADAPTS Pumping System for offloading Barge
1 Tug - Daring Class
1 Barge
1 Operations Manager
3 Equipment Operators
4 Laborers
Consumables

F. DISPOSAL

None

TABLE 39. EQUIPMENT AND LABOR ASSOCIATED WITH A 25% RESPONSE TO SCENARIO NO. 6 - UNIMAK PASS (Continued)

G. ANCILLARY

Communications Equipment

H. EMERGENCY EVACUATION

None

AD-A058 782 ARCTEC INC COLUMBIA MD F/G 13/2
SYSTEMS FOR ARCTIC SPILL RESPONSE. VOLUME I.(U)
MAR 78 L A SCHULTZ, P C DESLAURIERS DOT-CG-71343-A
UNCLASSIFIED 405C-3-VOL-1 USCG-D-44-78-VOL-1 NL

3 OF 4
AD
A058 782

COST OF SPILL RESPONSE

The costs associated with each level of response capability for each of the six oil spill scenarios were estimated in detail on the basis of the equipment and labor listings summarized in the preceding section of this report. All cost estimates were made in terms of current dollars at the time the work was done, early 1978. The staff of the Anchorage office of Crowley Environmental Services Corporation contributed to the determination of oil spill response costs in a major way. Assistance in determining spill response costs was also provided by McAllister Pollution Controls, Ltd. of Montreal, Quebec, Canada.

Since the great majority of the techniques and equipment called for in the preferred response scenarios are currently available, highly accurate costs were obtained from commercial oil spill response organizations on the basis of an hourly rental or usage charge. All cost figures were obtained from spill response operators and transportation organizations operating in Alaska. Charges associated with the use of equipment and personnel of the U.S. Coast Guard also were available on an hourly usage basis from Commandant's Instruction 16464.2A [17]. This document was the source, for example, for determining the cost of icebreaker support, and the cost of using the Coast Guard's Lockheed Clean Sweep Arctic Boat oil recovery device.

The preferred spill response scenarios also called for some equipment and techniques which are not currently available. Cost estimates for newly developed equipment included development, procurement, maintenance, staging, and operational costs. All of these cost components were then combined into a single rental or usage rate. All costs,including the cost of equipment to be developed in the future, were therefore handled in a common form, that of a commercial usage rate. The costs of consumables, such as food and fuel, were based on current purchase prices in Alaska.

While a substantial effort has been directed towards determining the total cost of each spill response effort as accurately as possible, it was recognized that the primary concern of this study was to determine the relative cost of each response effort as accurately as possible. Therefore, while the total cost of each spill response effort is judged to be reasonably complete and accurate, the primary emphasis was placed on the accuracy of relative, or comparative, costs between scenario-response level combinations.

Table 40 presents a summary of the costs associated with each response level for each oil spill response scenario described in the preceding section of this report. The costs are subdivided into the cost for each major function of the oil spill response effort including surveillance, containment, recovery, storage, transfer, disposal, logistics, ancillary and emergency evacuation. In this analysis, the cost of disposal is treated as a separate item only in those cases where physical recovery of the spilled oil into a temporary storage situation was involved. For those cases incorporating in situ disposal along with some degree of recovery of the oil, the disposal cost

TABLE 40. SUMMARY OF COSTS IN THOUSANDS OF DOLLARS BY SPILL RESPONSE FUNCTION FOR EACH SCENARIO-RESPONSE LEVEL COMBINATION

Scenario No.	1			2			3			4			5			6
Scenario	Beaufort Sea			Chukchi Sea			Norton Sound			Navarin Basin			Bristol Bay			Unimak Pass
Response Level, %	25	50	80	25	50	80	25	50	80	25	50	80	25	50	80	25
Surveillance	79	79	79	-	-	111	-	22	22	42	42	42	35	63	96	15
Containment	-	-	44	-	-	-	-	-	-	-	-	-	116	116	116	34
Recovery	175	571	761	33	238	370	27	830	1,085	817	826	1,090	446	1,007	2,265	126
Storage	-	-	10	-	-	-	-	18	-	9	-	-	96	204	108	14
Transfer	-	-	4	-	-	-	-	27	-	103	-	-	9	25	16	60
Disposal	-	-	7	-	-	-	-	10	-	-	-	-	23	47	24	-
Logistics	212	469	783	289	321	635	39	898	1,320	962	961	1,547	1,542	3,202	2,374	249
Ancillary	1	4	3	1	9	6	-	13	-	9	-	-	-	-	-	-
Emergency Evacuation	46	211	250	78	390	296	-	-	-	-	-	-	-	-	-	-
TOTAL	513	1,334	1,941	451	958	1,418	66	1,818	2,427	1,942	1,829	2,679	2,267	4,664	4,999	498

NOTE: Costs associated with shoreline cleanup and restoration were not included in this study.

is incorporated in with the recovery costs. As a result, for most of the scenario-response level combinations, the cost of disposal is incorporated in the recovery cost classification. The results summarized in this Table clearly emphasize the importance and cost of the logistics associated with oil spill response operations in the offshore regions of Alaska. In most cases, the costs associated with logistics are in the neighborhood of 50% of the total cost of oil spill response. The next major cost item is seen to be the cost of recovery operations, which includes the cost associated with in situ disposal. The total cost of oil spill response is seen to range from a low of $66,000 for the 25% response to the Norton Sound tanker casualty, to a maximum of $4,999,000 for the 80% response capability to the Bristol Bay oil well blowout.

The total costs of oil spill response are further analyzed in Table 41 which includes a summary of the volume of oil spilled for each scenario, and for each scenario-response level combination, the volume recovered, the volume remaining after a period of three months, the total cost of response, and the unit cost of response in terms of dollars per barrel of oil recovered. The unit cost of oil spill response operations is seen to range from less than $1.00 per barrel of oil recovered for the three response levels associated with the Chukchi Sea spill scenario, to $199.13 for the 25% response case for the Unimak Pass oil spill scenario.

The total cost of spill response is graphically presented in Figure 75 as a function of the percentage recovery of oil spilled for each of the six spill scenarios. For those oil spill scenarios for which the response scenario is a progressively more intensive application of the same basic technique the curves take a continuous shape, while for those scenarios which include significantly different techniques for the different levels of oil spill response, the curves take a more irregular shape, as is the case for Scenarios 3 and 4. These curves demonstrate the relatively low cost associated with oil spill response operations in the presence of stationary ice cover where the ice cover itself can be used as the operating platform, as demonstrated by the cost curves for the Beaufort Sea and Chukchi Sea scenarios, Scenarios 1 and 2. The very high cost of oil spill response associated with an oil spill in dynamic ice conditions is demonstrated by the cost curve for the Bristol Bay scenario, Scenario 5. The cost of response for the intermediate case of a broken ice field in a less dynamic situation is demonstrated by the intermediate costs associated with the tanker casualty scenarios of Norton Sound and the Navarin Basin, Scenarios 3 and 4. The cost of open water response corresponding to the Unimak Pass scenario, Scenario 6, is seen to be comparable, for the 25% response case, to the cost of the stationary ice response cases.

Figure 76 is a plot of the unit cost of oil spill response as a function of the percentage recovery of oil spilled for each of the six oil spill scenarios. The unit cost of recovery associated with the Chukchi Sea oil spill scenario is seen to be very low as a result of the great volume of oil associated with this scenario. The unit cost for a similar type of oil

TABLE 41. SUMMARY OF SPILL VOLUMES AND RESPONSE COSTS

Scenario Number	Scenario	Volume Spilled (bbl)	Response Level (%)	Volume Recovered (bbl)	Volume Left, 3 mo. (bbl)	Total Cost (K $)	Unit Cost ($/bbl recd.)
1	Beaufort Sea	15,000	0	0	10,000	0	-
			25	3,750	6,250	513	136.86
			50	7,500	2,500	1,334	177.90
			80	12,000	0	1,941	161.71
2	Chukchi Sea	2,225,000	0	0	2,068,500	0	-
			25	562,500	1,506,000	451	0.80
			50	1,125,000	943,500	958	0.85
			80	1,800,000	268,500	1,418	0.79
3	Norton Sound	50,000	0	0	33,500	0	-
			25	12,500	21,000	66	5.29
			50	25,000	8,500	1,818	72.72
			80	40,000	0	2,427	60.68
4	Navarin Basin	50,000	0	0	33,500	0	-
			25	12,500	21,000	1,942	155.39
			50	25,000	8,500	1,829	73.18
			80	40,000	0	2,679	66.97
5	Bristol Bay	225,000	0	0	158,400	0	-
			25	56,250	102,150	2,267	40.31
			50	112,500	45,400	4,664	41.46
			80	180,000	0	4,999	27.77
6	Unimak Pass	10,000	0	0	0	0	-
			25	2,500	0	498	199.13

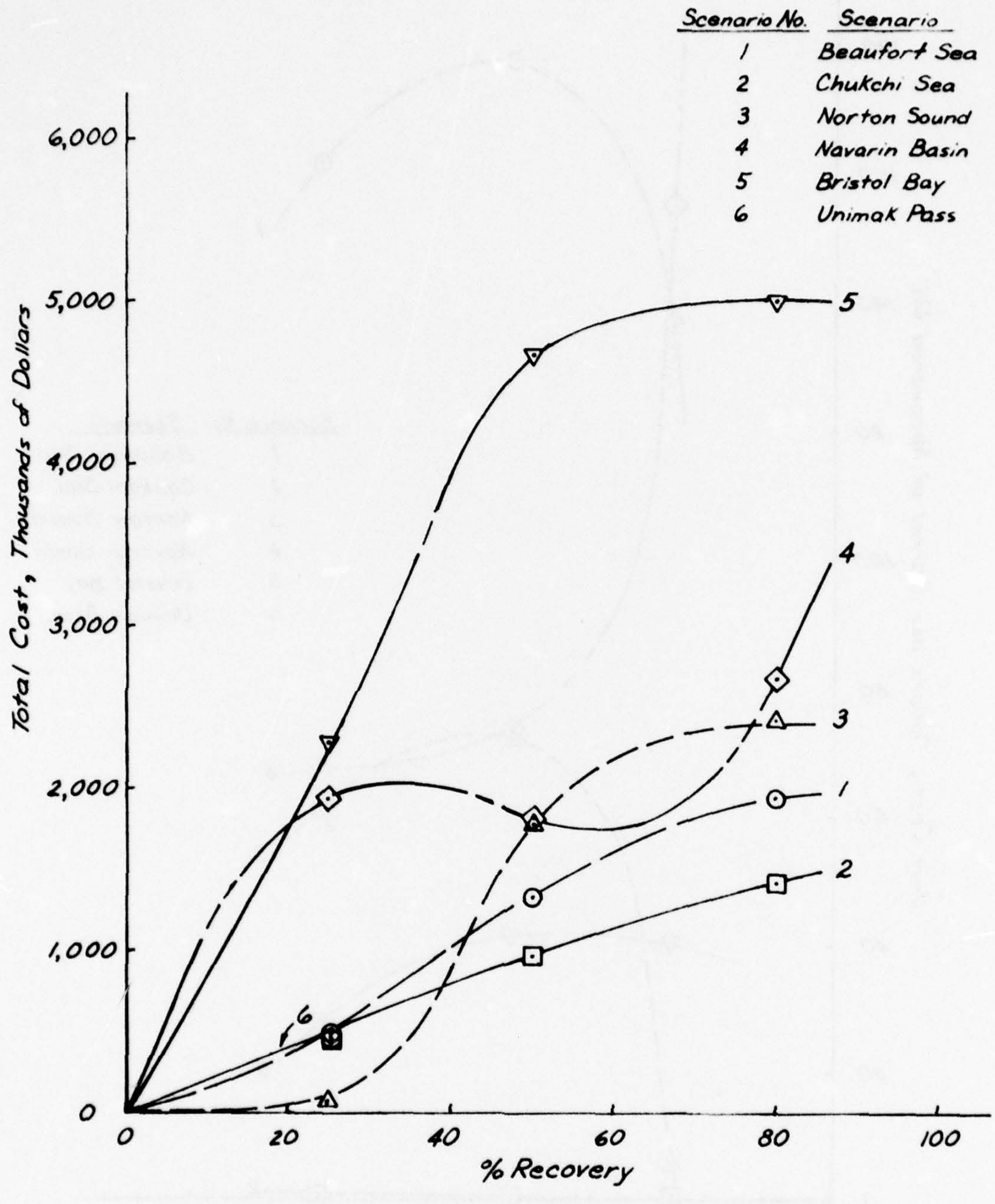


Figure 75. Total Cost of Response vs. Percentage Recovery of Oil Spilled For Each of the Six Scenarios

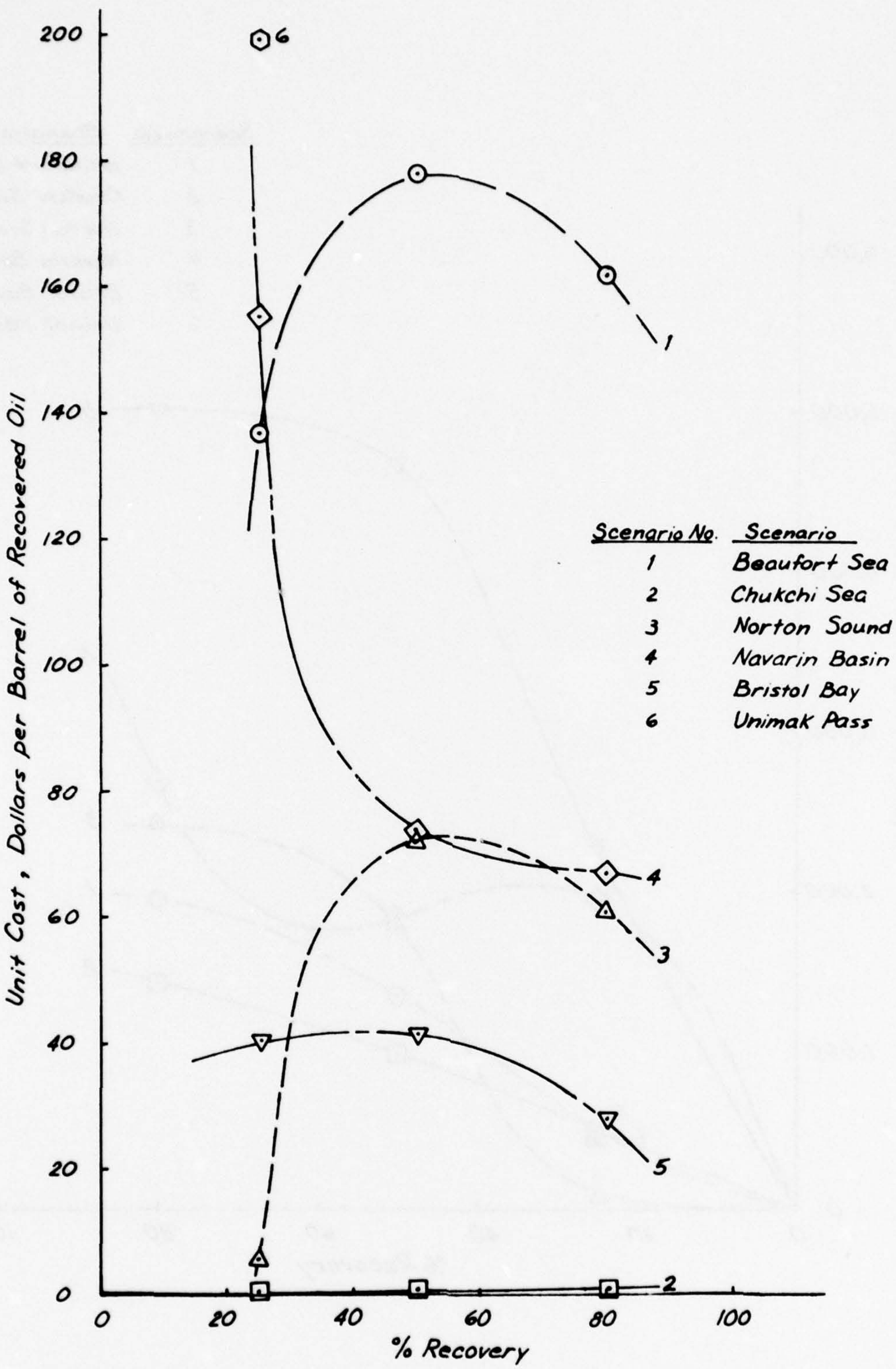


Figure 76. Unit Cost of Response vs. Percentage Recovery of Oil Spilled for Each of the Six Scenarios.

spill response involving a far lesser volume of oil is seen to be quite high as demonstrated by the unit cost curve for the Beaufort Sea scenario. The unit cost of oil spill response associated with the Bristol Bay scenario, consisting of a blowout from an average size reservoir, is also seen to be heavily influenced by the very large magnitude of the spill volume used as the base in the calculation of the unit cost. Again, intermediate results are seen to be achieved for the unit cost of response associated with the two tanker casualties at Norton Sound and in the Navarin Basin, although the unit cost of the 25% response case is seen to be drastically different. At this response level, the unit cost associated with the Navarin Basin response is very high, while the unit cost associated with the Norton Sound response is very low.

EFFECTIVENESS OF SPILL RESPONSE

The criteria for determining a system's effectiveness, and the methods for defining relative system effectiveness ratings, were not defined for this program, rather they were to be developed as part of the program. The evaluation of the effectiveness of the various spill response systems is perhaps the most difficult and most important task in any cost effectiveness analysis. The usefulness of the analysis depends almost entirely on the real meaningfulness of the effectiveness ratings.

For the purposes of this program, it was determined that the effectiveness of an oil spill response system should be based on a comparison of the impact of the spill on the environment with no response, to the impact the spill would have with the given response. The problem then becomes one of developing a meaningful definition of impact. Several expressions were developed for consideration as a spill impact index during the program. The more promising of these indexes are summarized in Table 42 along with the advantages and disadvantages associated with using each definition. Formulation 1 consists of an index based upon the volume of spilled oil which still remains unrecovered, undisposed of, or unweathered after a period of three months. The three month limit on projecting the behavior of the spilled oil was selected as a practical limit for making such projections with even a rough degree of accuracy. The primary advantage of this index formulation is seen to be its simplicity, while it has the major disadvantages of not accounting for differences in areal coverage, residence time, and the ecological sensitivity of the area. Formulation 2 consists of a summation over the three month period of the product of the average volume remaining and the ecological sensitivity index as defined and quantified earlier in this report. While this formulation more completely accounts for residence time and incorporates the ecological sensitivity factor, it still does not account for differences in areal coverage. Formulation 3 consists of a summation over the three month period of the average volume per month remaining times the average areal coverage for each month times the ecological sensitivity index for the month. This definition accounts for the volume of the spill, the areal coverage of the spill, the residence time, and the ecological sensitivity of the area. Whether the potential impact due to an oil spill is increased as the areal coverage is increased, or whether it is increased as the concentration is increased, is the subject of debate and is likely dependent upon site-specific ecological factors. A definition of impact corresponding to the concentration theory is presented as Formulation 4, where the index is presented as the summation over a three month period of the average volume remaining for each month divided by the average area of coverage for each month with the result multiplied by the ecological sensitivity index. Since the volume divided by the area is simply the thickness of the spill, differences between the solid ice cover, broken ice cover, and open water cases are emphasized with this definition. However, the spill impact is then only a function of the spill thickness and the ecological sensitivity index. In evaluating these four possible formulations of an oil spill impact index, it was judged that due to the nearshore proximity of all of the oil spill scenarios except the Navarin Basin scenario, it is likely that the more serious ecological damage would result from

TABLE 42. COMPARISON OF POSSIBLE DEFINITIONS OF AN OIL SPILL IMPACT INDEX

FORMULATION NO.	FORMULATION	ADVANTAGES	DISADVANTAGES
1	Volume Remaining after 3 months	Simplicity	Does not account for differences in ecological sensitivity. Does not account for differences in areal coverage. Does not account for residence time.
2	$\sum_{3\ \text{months}} \text{Volume} \times \text{ESI}$	Accounts for residence time. Accounts for ecological sensitivity of area.	Does not account for differences in areal coverage.
3	$\sum_{3\ \text{months}} \text{Volume} \times \text{Area} \times \text{ESI}$	Accounts for residence time. Accounts for ecological sensitivity. Accounts for areal coverage.	
4	$\sum_{3\ \text{months}} \frac{\text{Volume}}{\text{Area}} \times \text{ESI}$	Emphasizes differences between solid ice cover, broken ice cover and open water cases.	Thickness becomes the only physical spill characteristic of importance.

ESI = Ecological Sensitivity Index

a high areal coverage spill rather than a high concentration of pollutant spill. Therefore, the impact index selected for this study was Formulation 3, which relates the impact of a spill to the summation over a three month period of the average volume remaining times the average areal coverage times the ecological sensitivity index. It is emphasized that this expression for impact is selected for the purposes of this analysis, and is not intended to be in any way a general definition of oil spill impact. It is felt, however, that this formulation for impact will provide the best relative relationship between the impact for the various oil spill scenarios for the purposes of this analysis.

With this definition of an index for oil spill impact, alternative ways of formulating the effectiveness index were evaluated. The alternatives are summarized in Table 43 with their advantages and disadvantages. Formulation 1, consisting of the ratio of impact with no response to impact with response, has the advantage of increasing as the oil spill recovery increases, however this index does not go to zero for the case of zero oil recovery, and it can be indeterminate in some situations. Formulation 2, consisting of the same ratio minus 1, still increases with increasing oil spill recovery and goes to zero for the case of zero oil spill recovery, however, it also has the disadvantage of possibly being indeterminate. Formulation 3, consisting of one minus the ratio of impact with response to the impact with no response, gives an index which is zero for the case of zero recovery, increases as the oil spill recovery increases, and does not become indeterminate in any situation. Formulation 4, consisting of the ratio of impact with response to the impact with no response, has the advantage that it does not become indeterminate, however, it has the disadvantages that the numerical value of the index decreases as the oil spill recovery increases, and it does not go to zero for the case of zero oil spill response. Based on this comparison, Formulation 3 was judged to be the most desirable, therefore, the effectiveness index used in this study was defined as one minus the ratio of the impact with response to the impact with no response.

Using the definitions of spill impact index and spill response effectiveness index selected above, numerical values of the average area, average volume, and ecological sensitivity index are presented in Table 44 for each of the three months considered in the spill response effort, and the resulting spill impact indexes and response effectiveness indexes are presented for each oil spill scenario-response level combination. All values of average area in the table are in units of square miles, and all values of average volume are in units of thousands of barrels. The spill impact indexes are seen to be greatest for Scenarios 2 and 5, the two scenarios associated with oil well blowouts. This is to be expected since both the volume and the area of coverage for the massive spills are very high. Intermediate levels of impact index are seen to be obtained for the two tanker casualties, and the relatively low volume open water spill at Unimak Pass. The lowest value of spill impact index is obtained for the Beaufort Sea scenario due to the relatively small volume of the spill, the limited areal coverage due to containment by the ice cover, and the relatively low ecological sensitivity of the area. It is also noted that the ecological sensitivity plays a major role in only one scenario, the Unimak Pass scenario, and a lesser but still significant role in only one other scenario, the Norton Sound scenario. In all other cases, the spill is associated with a combination

TABLE 43. COMPARISON OF POSSIBLE DEFINITIONS OF AN OIL SPILL RESPONSE EFFECTIVENESS INDEX

FORMULATION NO.	FORUMLATION	ADVANTAGES	DISADVANTAGES
1	$\frac{\text{Impact with No Response}}{\text{Impact with Response}}$	Increases with increasing oil recovery.	Does not go to zero for zero recovery. Can be indeterminate.
2	$\frac{\text{Impact with No Response}}{\text{Impact with Response}} - 1$	Increase with increasing oil recovery. Goes to zero for zero oil recovery.	Could be indeterminate.
3	$1 - \frac{\text{Impact with Response}}{\text{Impact with No Response}}$	Goes to zero for zero recovery. Increases with increasing oil recovery. Does not become indeterminate.	
4	$\frac{\text{Impact with Response}}{\text{Impact with No Response}}$	Does not become indeterminate.	Decreases with increasing oil recovery. Does not go to zero for zero oil recovery.

TABLE 44. SPILL IMPACT AND RESPONSE EFFECTIVENESS INDEXES

Scenario No.	Response Level	Month 1 A avg	Month 1 V avg	Month 1 ESI	Month 2 A avg	Month 2 V avg	Month 2 ESI	Month 3 A avg	Month 3 V avg	Month 3 ESI	Spill Impact Index	Response Effectiveness Index
1	0%	0.0319	14.55	1	0.0357	13.05	1	0.0628	11.00	1	1.621	0
1	25%	0.0275	12.05	1	0.0212	9.30	1	0.0165	7.25	1	0.6484	0.6000
1	50%	0.0246	10.80	1	0.0127	5.55	1	0.0080	3.50	1	0.3642	0.7753
1	80%	0.0246	10.80	1	0.0127	5.55	1	0.0011	5.00	1	0.3419	0.7891
2	0%	0.2740	675	1	0.8210	1,765	1	0.8210	2,130	1	3,383	0
2	25%	0.2740	675	1	0.8210	1,765	1	0.8131	1,568	1	2,908	0.1401
2	50%	0.1370	337	1	0.4105	882	1	0.4105	1,005	1	820.8	0.7574
2	80%	0.1370	337	1	0.4105	882	1	0.4105	780	1	728.4	0.7847
3	0%	0.0285	47.75	1	0.1790	40.00	3	0.3065	35.50	2	44.60	0
3	25%	0.0040	38.35	1	0.0405	27.50	3	0.1985	23.00	2	12.63	0.7169
3	50%	0.0039	36.88	1	0.0286	19.38	3	0.0906	10.50	2	3.709	0.9168
3	80%	0.0035	33.13	1	0.0118	8.13	3	0	0	2	0.4038	0.9909
4	0%	0.0272	47.50	1	0.0629	41.25	1	0.1849	35.00	1	10.36	0
4	25%	0.0272	41.25	1	0.0440	28.75	1	0.1187	22.50	1	5.058	0.5117
4	50%	0.0272	35.00	1	0.0249	16.25	1	0.0528	10.00	1	1.884	0.8181
4	80%	0.0272	35.00	1	0.0153	10.00	1	0	0	1	1.105	0.8933
5	0%	0.3747	77.50	1	0.9864	178.8	1	1.355	187.3	1	459.2	0
5	25%	0.2839	58.74	1	0.7082	131.9	1	0.9316	131.1	1	232.2	0.4943
5	50%	0.1933	39.98	1	0.4564	85.0	1	0.5317	74.8	1	86.29	0.8121
5	80%	0.0844	17.47	1	0.1543	28.7	1	0.0519	7.3	1	6.282	0.9863
6	0%	0.5040	1.667	9	0	0	5	0	0	4.5	7.556	0
6	25%	0.3776	1.250	9	0	0	5	0	0	4.5	4.249	0.4377

A average in Square Miles
V average in 1,000 Barrels
ESI can vary from 1 to 10

of geographic area and time of year which results in the lowest level of ecological sensitivity index of 1. In spite of the very high ecological sensitivity index for the Unimak Pass scenario, the spill impact index is still relatively low because all of the Arctic diesel fuel spilled evaporates within a 10 day period even if no spill response effort whatsoever is exerted.

The final column of Table 44 presents the oil spill response effectiveness index for each combination of spill scenario and response level. The very wide variation in the numerical value of the spill impact index is seen to be normalized out in the calculational procedure leading to the oil spill response effectiveness index. In each case, by definition, the zero response level produces an effectiveness index of zero. As the level of response increases, the effectiveness index increases. The maximum effectiveness index for the cases under consideration are obtained for the 80% response level in the Norton Sound scenario, and the 80% response level in the Bristol Bay scenario.

The oil spill response effectiveness indexes are displayed as a function of the percentage recovery of oil spilled for each of the six oil spill scenarios in Figure 77. The peculiar shape of the curve for the Chukchi Sea scenario is a result of the unique situation associated with the 25% response case for this scenario. In this situation, oil is burned in situ in the melt hole created in the ice cover after the oil well blowout has been arrested, however, the areal coverage of the spill remains the same as in the zero recovery case. This results in a relatively low value for the spill effectiveness index for this situation. The greatest improvement in effectiveness index as the percentage recovery increases over the range of 50 to 80% is seen to be for the Bristol Bay scenario. It is also noticed that for oil response levels greater than 25%, all scenarios exhibit the same trend of diminishing returns in terms of effectiveness as the recovery level increases.

The oil spill response effectiveness index for Scenarios 3 and 5 are seen to approach 1.0. This results from a combination of low volumes and areal coverages for a significant portion of the three month evaluation period. The responses for Scenarios 1 and 2 at the higher levels of recovery are least effective since the areal coverage remains large even though 80% of the oil spilled is recovered.

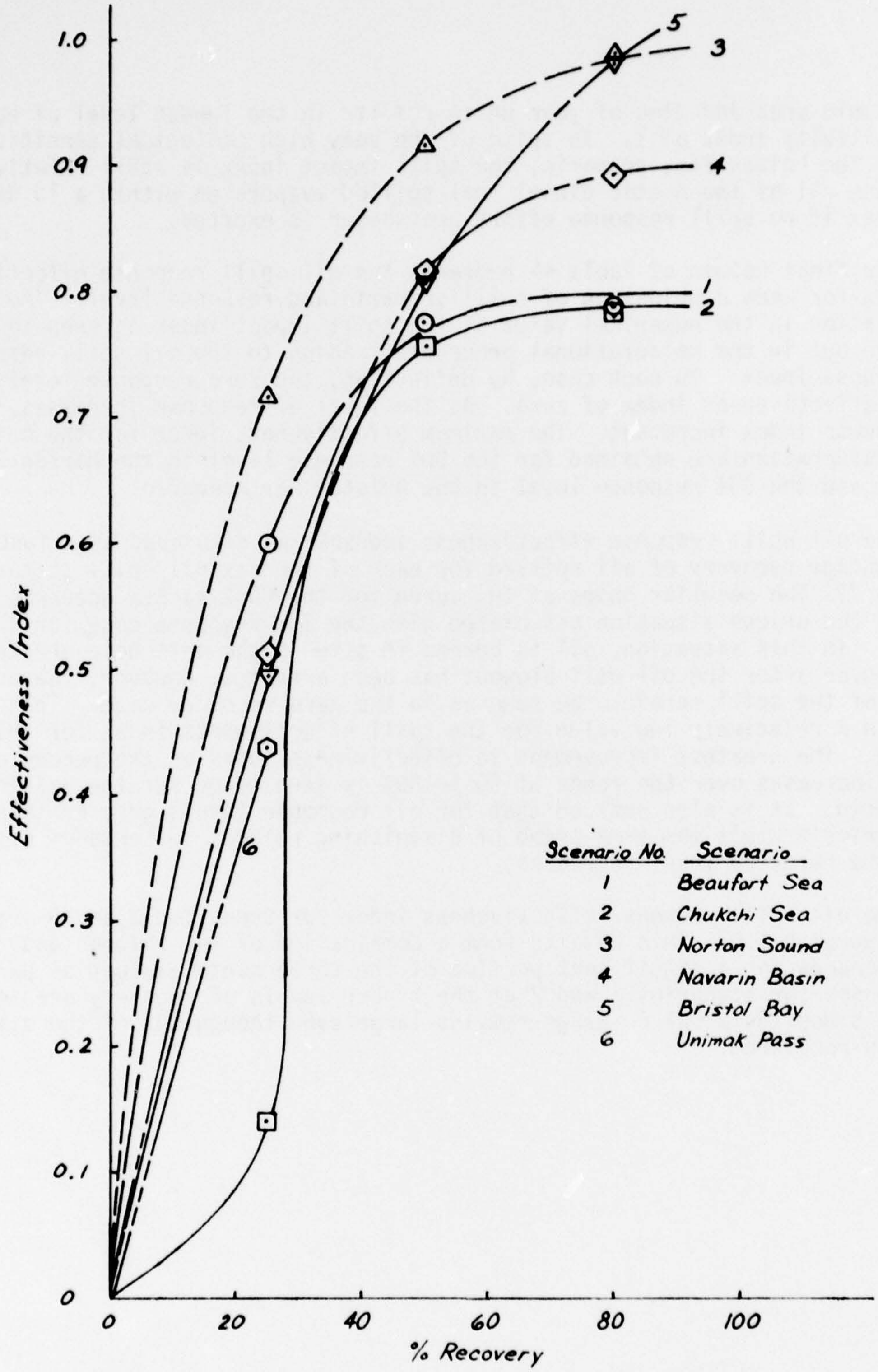


Figure 77. Effectiveness Index vs. Percentage Recovery of Oil Spilled for Each of the Six Scenarios.

SELECTION OF AN ARCTIC OIL SPILL RESPONSE SYSTEM

One of the objectives of this program was to determine the most cost effective, environmentally compatable, and technically feasible Coast Guard arctic pollution response system that can be used in the projected scenarios to recover and dispose of spilled oil. The original program plan called for the development of four alternative Coast Guard arctic spill response systems, and the selection of an optimum system based upon a cost effectiveness analysis.

Table 45 summarizes the costs and effectiveness indexes obtained for each of the sixteen combinations of oil spill scenario and response level. The sixteen cases result from three levels of response capability for each of Scenarios 1 through 5, and one level of response capability for Scenario 6. The total cost of maximum response for all six scenarios is seen to be about $14,000,000, and the maximum possible effectiveness obtained by adding the effectiveness index for each maximum case is seen to be 4.882.

All costs that are used in the analysis are additive since all costs are on a rental basis. Therefore, although similar equipment may be used in several cases there is no correction or modification for duplication of equipment or commonality of approach since the pertinent cost is the cost of oil spill response, rather than the investment cost in equipment for oil spill response, or any other individual cost component.

Table 46 is a summary of the normalized cost, the normalized effectiveness, and the resulting cost effectiveness index, based upon the normalized cost and normalized effectiveness, for each of the sixteen cases of oil spill scenario and response level. The normalized values were obtained by dividing the individual values of cost and effectiveness by the maximum cost and the maximum possible effectiveness respectively. The resulting cost effectiveness indexes are seen to range from a least cost effective value of 1.772 for the 80% response level to Scenario 5, to the most cost effective value of 0.034 for the 25% response level to Scenario 3.

Figure 78 is a plot of these cost effectiveness indexes as a function of the percentage of spilled oil recovered for each of the six oil spill scenarios. The curves show the cost effectiveness to be optimized for Scenarios 2 and 4 at the 50% recovery level, while the cost effectiveness is minimized at the 25% response level for Scenarios 1, 3, 5 and 6.

Now that the cost effectiveness index for each of the sixteen cases has been determined, it is necessary to combine the oil spill response capability of these sixteen cases into alternative response systems. The original program plan called for the development of four alternative Coast Guard arctic spill response systems having various levels of response capability and various degrees of system sophistication. The optimum Coast Guard arctic pollution response system was then to be selected from this group of four possible systems. Several methods for developing alternative oil spill response systems were considered, based upon combining the capabilities of the sixteen individual responses into systems in a cost effective manner. Many of the methods

TABLE 45. SUMMARY OF COSTS AND EFFECTIVENESS INDEXES FOR THE SIXTEEN COMBINATIONS OF OIL SPILL SCENARIO AND RESPONSE CAPABILITY

Scenario	Recovery Level %	Cost K$	Unit Cost $/bbl	Effectiveness Index
1	25	513	136.86	0.600
1	50	1,334	177.90	0.775
1	80	1,941	161.71	0.789
2	25	451	0.80	0.140
2	50	958	0.85	0.757
2	80	1,418	0.79	0.785
3	25	66	5.29	0.717
3	50	1,818	72.72	0.917
3	80	2,427	60.68	0.991
4	25	1,942	155.39	0.512
4	50	1,829	73.18	0.818
4	80	2,679	66.97	0.893
5	25	2,267	40.31	0.494
5	50	4,664	41.46	0.812
5	80	4,999	27.77	0.986
6	25	489	199.13	0.438

Cost of Maximum Response = 13,962 Effectiveness of Maximum Response = 4.882

TABLE 46. SUMMARY OF NORMALIZED COST, NORMALIZED EFFECTIVENESS, AND COST EFFECTIVENESS INDEX FOR THE SIXTEEN CASES

Scenario	Recovery Level %	Normalized Cost	Normalized Effectiveness	Cost Effectiveness Index
1	25	0.037	0.123	0.301
1	50	0.096	0.159	0.604
1	80	0.139	0.162	0.858
2	25	0.032	0.029	1.103
2	50	0.069	0.155	0.445
2	80	0.101	0.161	0.627
3	25	0.005	0.147	0.034
3	50	0.130	0.188	0.691
3	80	0.174	0.203	0.857
4	25	0.139	0.105	1.324
4	50	0.131	0.168	0.780
4	80	0.192	0.183	1.049
5	25	0.167	0.101	1.653
5	50	0.334	0.166	2.012
5	80	0.358	0.202	1.772
6	25	0.036	0.090	0.400

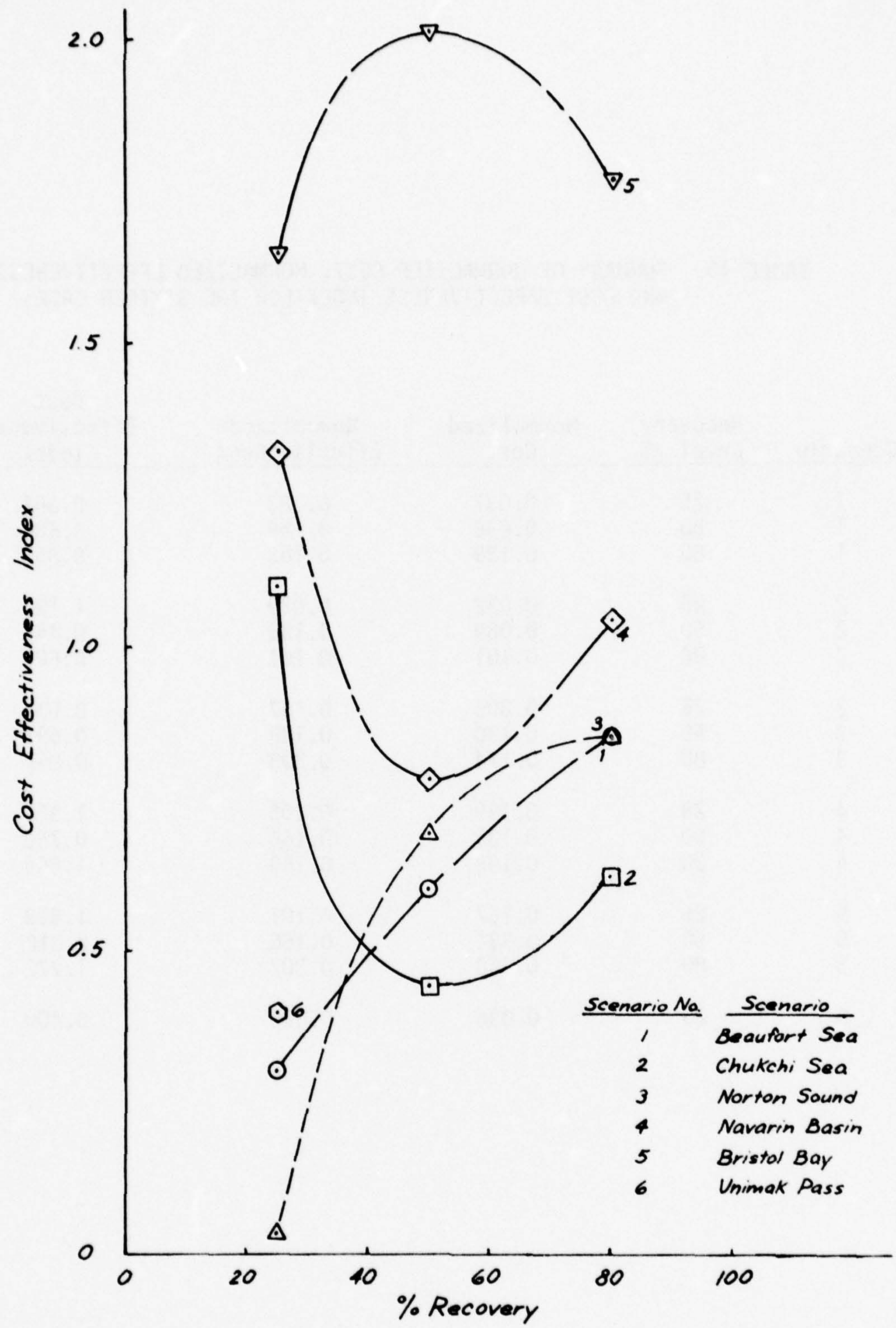


Figure 78. Cost Effectiveness Index vs. Percentage Recovery of Oil Spilled for Each of the Six Scenarios.

considered were found to be inadequate because the sixteen individual systems are not of a continuous nature, that is, the development of the systems do not progress in a consistent manner from one of minimum capability through continuous growth to one of maximum capability due to changes in the techniques used to achieve greater response levels. The approach toward developing combined systems found to be most promising was based on an initial recognition of a logical grouping of the sixteen systems combined with the requirement that all alternative systems have a minimum response capability for each of the six oil spill scenarios. This requirement therefore establishes a base case of 25% response capability for each of the six oil spill scenarios.

The complexity of the system building procedure can be substantially reduced by recognizing that the oil spill response scenarios are neither a continuous development of similar techniques and equipment, nor are they sixteen totally independent systems of techniques and equipment. Rather, the sixteen oil spill situations can logically be placed into three groups based upon similarities in response techniques. Oil spill Scenarios 1 and 2 have many similarities and can be placed into a common group designated as Group I. Both of these spills occur in the presence of stable ice conditions, both are near shore, and both allow the use of the ice cover itself as a working platform for much of the oil spill response effort. In addition, the projected oil spill behavior is similar in both cases, and the spill response crews are faced with recovering oil which is primarily under 4 to 6 feet of ice and concentrated in pockets formed by the undulating under surface of the ice. In addition, both spill response scenarios rely heavily upon in situ burning as the primary response technique.

Oil spill Scenarios 3 and 4 also have much in common and these have been combined into Group II. Both spills are located in the Bering Sea, and representative ice conditions for both consist primarily of ice floes interspersed with pressure ridges and rafted ice. Both spills consist primarily of a release of oil into a broken ice field formed by the ship's track, and in both cases winds and currents will likely result in the closure of the ship's track which would force the oil into pressure ridges, hummocks, and pools in rafted ice. The spill response for both scenarios is based on limited use of the ice cover itself as a working platform, and depends primarily upon the use of marine vehicles.

Scenarios 5 and 6 also have many similarities and have therefore been combined as Group III. In both cases, the environmental conditions are such that the spill behavior, and some spill response techniques, are associated with open water conditions. In this case, no operations of any kind are possible from the ice cover itself; the total response must be based from marine vessels, and the equipment used must be capable of recovering oil on open water.

This approach of combining the sixteen oil spill response cases into groups results in a reduction in the number of cases to be handled from sixteen to nine, where the nine cases result from three levels of response

capability for each of the three groups. These nine spill response systems can then be combined in a step-wise manner on the basis of cost effectiveness index to result in the identification of the most cost effective oil spill response system.

Since each candidate system must include at least a minimum response level capability for each of the six oil spill scenarios, System 1 was selected on the basis of providing a 25% response capability for all three groups, which interprets as a 25% response capability for all six oil spill scenarios. Within System 1, the subsystem components comprising the system were listed in a priority ranking based on a cursory evaluation of the time proximity of the spill situations. Based upon the information used in developing the six representative oil spill scenarios, the situations included in Group III include a current potential oil spill scenario, the open water spill of diesel fuel at Unimak Pass. The subsystem components obtained from Group III were therefore given highest priority in the order of listing subsystem components for System 1. The group having the next nearest proximity in time frame consists of Group I, since exploratory drilling is presently scheduled for 1980 in the nearshore Beaufort Sea. Subsystem components associated with Group I were therefore placed below the Group III components in developing the subsystem component listing for System 1. Subsystem components representing Group II were then given the lowest priority ranking on the list, since both of the scenarios comprising this group are tanker casualties, which, being dependent upon the marine transportation of crude oil, are not judged likely to occur before 1988.

Combining the sixteen individual response systems into nine combinations corresponding to three response levels for each of the three groups results in a breakdown of normalized cost and normalized effectiveness by group as summarized in Table 47. The resulting cost effectiveness index for each group-response level combination is then obtained as summarized in the final column of Table 47. The resulting cost effectiveness indexes are seen to range from a least desirable of 1.445 to a most desirable of 0.454. For ease of future reference, the remaining discussion will identify the 25% response capability by the letter A, 50% by the letter B, and 80% by the letter C. Therefore, the designation IA refers to that response capability necessary for achieving a 25% response level for each of the scenarios comprising Group I, Scenarios 1 and 2.

Based on the requirement of providing a minimum 25% response capability for each oil spill scenario, and with the subsystem components ordered in the priority ranking discussed above, System 1 provides response capability for Groups IIIA, IA and IIA in that order. The resulting normalized cost for System 1 is then 0.411, and the resulting normalized effectiveness is 0.595, which combine to give a normalized cost effectiveness index for System 1 of 0.691. The development of alternative systems then proceeds on the basis of replacing each group-response level combination by a higher capability combination, and determining which modification results in the most cost effective result for the revised system. The development of this procedure which results in the identification of 6 alternative arctic oil spill response systems is

TABLE 47. SUMMARY OF NORMALIZED COST AND EFFECTIVENESS, AND COST EFFECTIVENESS INDEX BY GROUP AND REPONSE LEVEL

GROUP	Response Level, %	Normalized Cost	Normalized Effectiveness	Cost/Effectiveness
	25	0.069	0.152	0.454
I	50	0.164	0.314	0.522
	80	0.241	0.322	0.749
	25	0.144	0.252	0.571
II	50	0.261	0.355	0.735
	80	0.366	0.336	0.948
	25	0.198	0.191	1.036
III	50	0.370	0.256	1.445
	80	0.370	0.256	1.350

summarized in Table 48. For example, System 2 is developed from System 1 by replacing the IA response by the IB response. This selection is made since it results in the most favorable cost effectiveness index of 0.668 for System 2. System 2 is then used as the basis for further system development into System 3, based on the minimum resulting cost effectiveness ratio, and systems are further developed until all combinations have been considered. Six alternative systems result since response IIIB was never included in any system because response IIIC proved to be more cost effective. Each progressive system represents the most effective unit increase in capability over the previous system. The total response capability varies from a minimum of 25% response for all three groups, to the maximum feasible response in all three groups which represents an 80% response for Scenarios 1 through 5, and a 25% response for Scenario 6.

On the basis of the preceding analysis, six alternative Coast Guard arctic pollution response systems have been identified. The makeup of these systems by group are summarized in Table 49, along with the resulting total cost of response for all six oil spill scenarios, the unit cost of response, and the cost effectiveness index for that system. The cost effectiveness values of Table 49 are plotted versus system number in Figure 79, which more graphically displays the range of cost effectiveness index covered by these six alternative spill response systems as applied to the six selected oil spill scenarios. System 2 is clearly identified as the optimum U.S. Coast Guard arctic pollution response system on the basis of its cost effectiveness. System 2, consisting of Groups I-B, II-A and III-A, therefore has the capability of providing a 25% response capability for Scenarios 3 through 6, consisting of Norton Sound, the Navarin Basin, Bristol Bay and Unimak Pass, and a 50% response capability for Scenarios 1 and 2, consisting of the Beaufort Sea and the Chukchi Sea.

Table 50 is a matrix presentation of oil spill response capability for the alternative oil spill response systems, ranked in the order of less desirable cost effectiveness. The fact that the most cost effective system corresponds more to a lower level of response capability rather than a higher level of response capability is supported by prior operating experience in oil spill recovery operations. As discussed previously in this report, the return in effectiveness for an increasing application of resources (costs) generally diminishes when higher recovery levels are the goal. Also, prior operating experience has proven that an oil spill response capability of greater than 25% is extremely difficult to achieve. The costs identified in the previous sections of this report reflect this fact.

The equipment accociated with each of the six alternative oil spill response systems is briefly outlined in Tables 51 through 56, with the equipment comprising the optimum arctic oil spill response system, System 2, presented first in Table 51. Items that require research and development are identified by an asterisk in these tables. All other spill response equipment listed is in the realm of current capability although evaluative testing and demonstration programs may be required in many cases before it can be determined whether or not this equipment can be applied in the manner proposed. Such cases are identified by double asterisks in the tables.

TABLE 48. DEVELOPMENT OF ALTERNATIVE SPILL RESPONSE SYSTEMS ON A COST-EFFECTIVENESS BASIS

System 1 = IIIA + IA + IIA

Revision:

System	Normalized Cost	Normalized Effectiveness	Cost/Effectiveness
System 1	0.411	0.595	0.691
System 1 + IB	0.506	0.757	0.668
System 1 + IIB	0.528	0.698	0.756
System 1 + IIIB	0.583	0.660	0.883
System 1 + IC	0.583	0.765	0.762
System 1 + IIC	0.633	0.729	0.868
System 1 + IIIC	0.607	0.696	0.872

System 2 = IIIA + IB + IIA

Revision:

System	Normalized Cost	Normalized Effectiveness	Cost/Effectiveness
System 2	0.506	0.757	0.668
System 2 + IIB	0.623	0.860	0.725
System 2 + IIIB	0.678	0.822	0.825
System 2 + IC	0.583	0.765	0.762
System 2 + IIC	0.728	0.891	0.817
System 2 + IIIC	0.702	0.858	0.818

System 3 = IIIA + IB + IIB

Revision:

System	Normalized Cost	Normalized Effectiveness	Cost/Effectiveness
System 3	0.623	0.860	0.725
System 3 + IIIB	0.795	0.925	0.859
System 3 + IC	0.872	0.933	0.935
System 3 + IIC	0.728	0.891	0.817
System 3 + IIIC	0.819	0.961	0.853

System 4 = IIIA + IB + IIC

TABLE 48. DEVELOPMENT OF ALTERNATIVE SPILL RESPONSE SYSTEMS ON A COST-EFFECTIVENESS BASIS (Continued)

Revision:

System	Normalized Cost	Normalized Effectiveness	Cost/Effectiveness
System 4	0.738	0.891	0.817
System 4 + IC	0.805	0.899	0.895
System 4 + IIIB	0.900	0.956	0.942
System 4 + IIIC	0.924	0.992	0.931

System 5 = IIIA + IIC + IC

Revision:

System	Normalized Cost	Normalized Effectiveness	Cost/Effectiveness
System 5	0.805	0.899	0.895
System 5 + IIIB	0.977	0.964	1.013
System 5 + IIIC	1.000	1.000	1.000

System 6 = IIC + IC + IIIC

TABLE 49. SUMMARY OF THE SIX ALTERNATIVE U.S. COAST GUARD ARCTIC SPILL RESPONSE SYSTEMS APPLIED TO THE SIX OIL SPILL SCENARIOS

System	Groups Included	Total Cost K$	Unit Cost $/bbl	Cost/Effectiveness
1	IA, IIA, IIIA	5,738	8.83	0.691
2	IB, IIA, IIIA	7,067	5.81	0.668
3	IB, IIB, IIIA	8,705	7.01	0.725
4	IB, IIC, IIIA	10,164	8.00	0.817
5	IC, IIC, IIIA	11,230	5.76	0.895
6	IC, IIC, IIIC	13,962	6.73	1.000

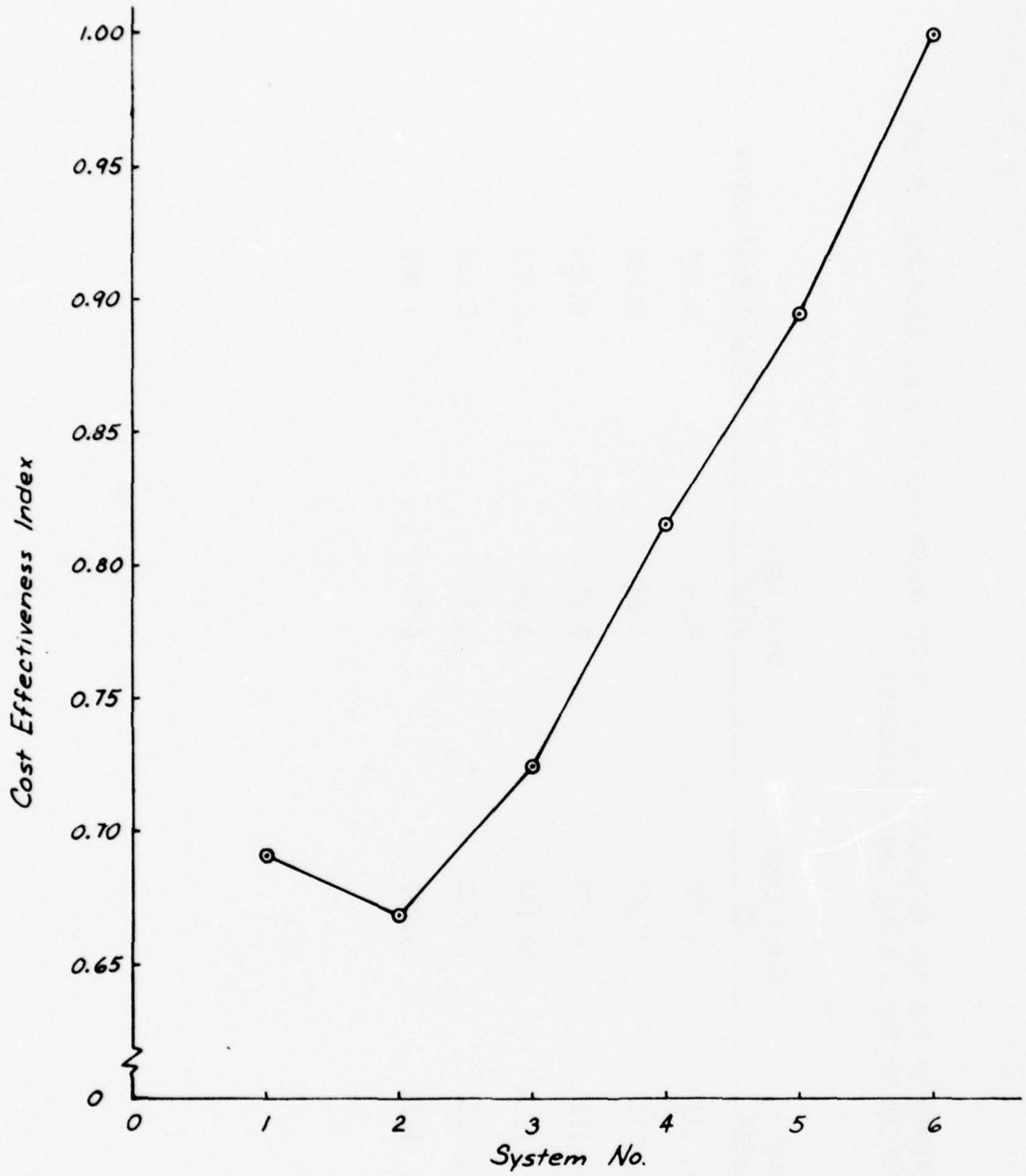


Figure 79. Comparison of Cost Effectiveness Index for the Six Alternative Response Systems.

TABLE 50. OIL SPILL RESPONSE LEVELS FOR THE SIX ALTERNATIVE SYSTEMS APPLIED TO THE SIX REPRESENTATIVE OIL SPILL SCENARIOS

SYSTEM	SCENARIO 1	SCENARIO 2	SCENARIO 3	SCENARIO 4	SCENARIO 5	SCENARIO 6
System 2	50%	50%	25%	25%	25%	25%
System 1	25%	25%	25%	25%	25%	25%
System 3	50%	50%	50%	50%	25%	25%
System 4	50%	50%	80%	80%	25%	25%
System 5	80%	80%	80%	80%	25%	25%
System 6	80%	80%	80%	80%	80%	25%

TABLE 51. EQUIPMENT REQUIRED FOR THE OPTIMUM OIL SPILL RESPONSE SYSTEM - SYSTEM 2

RANKING: 1

Response Type	Surveillance	Containment	Recovery	Storage	Transfer	Disposal	Logistics	Ancillary	Emergency Evacuation
I	*Under-ice markers (1,500) Diving equipment (8 sets) Nodwell drill (1) *Special systems for detecting oil under ice (3)		**Large downhole drills (2) Bulldozers (2) Diving equipment **Nodwell drill *Means to direct oil under ice into holes (8) Skimmer heads			Diesel fuel (1,700 gals)	C-130 (1) Helicopter (1) Generators (4) *Special clothing Crew Transport vehicle (1) Grader (1) Portable water pumps (3) Heaters Portable shelters (6)	Aircraft radio beacons (2) Weather forecasts Communications equipment	Helicopter Individual emergency beacons
II	Surface markers (750) Hand held augers (27) Chain saws (27)		Skimmer heads (18) Hand held augers Chain saws	Cement troughs (50)	*Transfer systems for high viscosity oil (18) 100' hoses (18)	**Incendiary devices (1,000)	Helicopter Polar ice-breaker (1) *Special clothing (73 sets)	Weather forecasts Ice forecasts Communications equipment	Helicopter Individual emergency beacons (73)
III	Fixed wing aircraft (1) Surface markers (100)	**Conventional high seas boom suitable for use in light ice fields (2,400 ft.)	**Conventional recovery devices (4)	Tank barges (4)	Conventional pumps (4) ADAPTS (1)	**Open flame burner system (1)	Tugs (12) C-130 Generators Light plants (4) Heaters (8)	Weather forecasts Ice forecasts Communications equipment	

NOTE: Numbers in brackets are totals for all Subsystems and Groups; items without numbers are duplicates, already listed in other Groups or Subsystems.
* Research and development required.
** Demonstration required.

TABLE 52. EQUIPMENT FOR OIL SPILL RESPONSE SYSTEM 1 - VARIATIONS FROM THE OPTIMUM SYSTEM

RANKING: 2

Response Type	Surveillance	Containment	Recovery	Storage	Transfer	Disposal	Logistics	Ancillary	Emergency Evacuation
I	DELETE: *Special systems for detecting oil under ice (3)		ADD: Front end loader (1) DELETE: **Large downhole drill (2)				ADD: Generators (3) Light plants(6) DELETE: Portable shelters (2)		
II									
III									

NOTE: Numbers in brackets are totals for all Subsystems and Groups; items without numbers are duplicates, already listed in other Groups or Subsystems.
* Research and development required.
** Demonstration required.

TABLE 53. EQUIPMENT FOR OIL SPILL RESPONSE SYSTEM 3 - VARIATIONS FROM THE OPTIMUM SYSTEM

RANKING: 3

Response Type	Surveillance	Containment	Recovery	Storage	Transfer	Disposal	Logistics	Ancillary	Emergency Evacuation
I									
II			ADD: *Oil/ice recovery vessel (1)	ADD: **Bladder tanks on sleds (14)	ADD: Conventional pumps (10)		ADD: *Special clothing (41 sets) Light plants (6)	ADD: *Oil spill behavior model	ADD: Individual emergency beacons(41)
	DELETE: Augers (8) Chain Saws(10)		DELETE: Augers Chain Saws Skimmer heads (4)	DELETE: Cement troughs (50)	DELETE: *Transfer systems for high viscosity oil (18)				
III									

NOTE: Numbers in brackets are totals for all Subsystems and Groups; items without numbers are duplicates, already listed in other Groups or Subsystems.
* Research and development required.
** Demonstration required.

TABLE 54. EQUIPMENT FOR OIL SPILL RESPONSE SYSTEM 4 - VARIATIONS FROM THE OPTIMUM SYSTEM

RANKING: 4

Response Type	Surveillance	Containment	Recovery	Storage	Transfer	Disposal	Logistics	Ancillary	Emergency Evacuation
I									
II	DELETE: Augers (27) Chain saws (27)		ADD: *Oil/ice recovery vessel (1) DELETE: Skimmer heads (16) Augers Chain saws	DELETE: Cement troughs (50)	DELETE: *Transfer systems for high viscosity oil (18)		DELETE: *Special clothing (57 sets)	ADD: *Oil spill behavior model	DELETE: Individual emergency beacons (57)
III									

NOTE: Numbers in brackets are totals for all Subsystems and Groups; items without numbers are duplicates, already listed in other Groups or Subsystems.
* Research and development required.
** Demonstration required.

TABLE 55. EQUIPMENT FOR OIL SPILL RESPONSE SYSTEM 5 - VARIATIONS FROM THE OPTIMUM SYSTEM

RANKING: 5

Response Type	Surveillance	Containment	Recovery	Storage	Transfer	Disposal	Logistics	Ancillary	Emergency Evacuation
I	ADD: Surface markers (1,250) Nodwell drill (1)		ADD: *Large down-hole drills (2)	ADD: Towable bladder tanks (5)	ADD: Oil/water separator (1) Portable pumps (3)		ADD: Generators (4) Light plants (2) Floating platforms (2) Sky crane helicopter (1)		
II	DELETE: Augers (27) Chain saws (27)		ADD: *Oil/ice recovery vessel (1) DELETE: Skimmer heads (16) Augers Chain saws	DELETE: Cement troughs (50)	DELETE: *Transfer systems for high viscosity (18)		DELETE: *Special clothing (57 sets)	ADD: Oil spill behavior model	DELETE: Individual emergency beacons (57)
III									

NOTE: Numbers in brackets are totals for all Subsystems and Groups; items without numbers are duplicates, already listed in other Groups or Subsystems.
* Research and development required.
** Demonstration required.

TABLE 56. EQUIPMENT FOR OIL SPILL RESPONSE SYSTEM 6 - VARIATIONS FROM THE OPTIMUM SYSTEM

RANKING: 6

Response Type	Surveillance	Containment	Recovery	Storage	Transfer	Disposal	Logistics	Ancillary	Emergency Evacuation
I	ADD: Surface markers (1,250) Nodwell drill (1)		ADD: **Large downhole drills (2)	ADD: Towable bladder tanks (5)	ADD: Oil/water separator (1) Vacuum pumps (3)		ADD: Generators (4) Light plants (2) Floating platforms (2) Sky crane helicopter (1)		
II	DELETE: Augers (27) Chain saws (27)		ADD: *Oil/ice recovery vessel (1) DELETE: Skimmer heads (16) Augers Chain saws	DELETE: Cement troughs (50)	DELETE: *Transfer systems for high viscosity oil (18)		DELETE: *Special clothing (57 sets)	ADD: *Oil spill behavior model	DELETE: Individual emergency beacons (57)
III	ADD: Electronic surveillance device (1)		ADD: *Oil/ice recovery vessel Adsorbent material (180 ctns.)	ADD: Waste drums (40)	ADD: Conventional pumps (2)			ADD: *Oil spill behavior model	

NOTE: Numbers in brackets are totals for all Subsystems and Groups; items without numbers are duplicates, already listed in other Groups or Subsystems.
* Research and development required.
** Demonstration required.

DEVELOPMENT OF SUBARCTIC SPILL AND SPILL RESPONSE SCENARIOS

Introduction

While the primary emphasis of this program was placed on the coastal and offshore regions of Alaska, it was recognized that the approaches developed for oil spill response in offshore Alaska may be applicable to some degree in other subarctic ice infested waters of the lower 48 states. This program therefore included a task having the objective of evaluating the alternative Coast Guard arctic oil spill response systems for application in seasonally ice infested waters of the lower 48 states. The alternative arctic systems were to be evaluated against subsystem performance criteria developed for the subarctic applications, and changes or additions in the optimum Coast Guard arctic pollution response system were to be identified so that the arctic system could be adapted for subarctic applications.

The approach used in the development of subarctic system requirements closely paralleled the approach previously described for establishing arctic system requirements with the study based on selected oil spill scenarios. The selection of the location for the subarctic spills was based upon establishing a representative range of environmental conditions for the study, and the selection of the spill situation was based upon the history of spills in the ice infested waters of the subarctic regions. Representative oil spill scenarios were selected, and alternative and preferred oil spill response scenarios were developed. System and subsystem performance requirements were then established on the basis of these preferred subarctic spill response scenarios. The following section of this report is concerned with the adaptation of the arctic spill response systems for subarctic applications.

In order to obtain a representative range of environmental and spill conditions associated with subarctic ice infested waters, this study concentrated on three regions including the Great Lakes, the northern rivers, and northern coastal regions. The Great Lakes are probably the most prominent seasonally ice infested waters of the contiguous 48 states. The weather experienced in the Great Lakes region during the winter of 1976-1977 clearly demonstrated the potential oil spill problems associated with operations in that region. Ice conditions in that severe winter resulted in the extended shipping season almost being discontinued. The only traffic maintained on the lakes was that of fuel oil tankers, required because of the shortage of fuel in the northern communities of Michigan. These tankers were escorted through the most severe ice conditions that had been experienced on the lakes in over 100 years. The fact that these tankers were required to transit the Great Lakes even in such severe ice conditions demonstrates the need for a winter oil spill response capability in the Great Lakes region. Recent winters have also resulted in some of the most severe freeze-ups of the northern rivers of the contiguous 48 states that have been experienced in many years. Fuel barge traffic on the northern rivers always presents the possibility of a major oil spill. The northern coastal areas also experienced the most severe ice conditions in over 10 years during January and February of 1977. Again, fuel oil barges in local transport, and ocean going tankers, present the possibility of oil spills in ice infested waters along the northern coastal regions. The problems addressed in responding to oil spills in ice infested waters in each

of these three regions could be quite distinct from each other, and also quite distinct from the problems to be encountered in offshore and coastal Alaska. The differences and similarities in conditions, and in oil spill response approach, are outlined in the following sections of this report.

Great Lakes Region

Description of Region

The Great Lakes Basin comprises the five Great Lakes and their connecting channels, and a land area of about 298,000 square miles drained by the waterway above Ogdensburg, New York. The basin's population in 1970 was 29,332,000, about 14.4 percent of the total U.S. population. The basin contains several national industrial centers and is oriented towards manufacturing. Nearly four million persons, 35 percent of the basin's labor force, are employed in manufacturing. In addition, the basin contains extensive mineral, forest, and agricultural resources.

The Great Lakes Region is considered to be a 19-state economically dependent tributary area. This includes the eight border states and the eleven adjacent states. This nineteen-state region generates about 25 percent of the nation's general cargo traffic. Approximately one-half of this traffic has a transportation cost advantage using the Great Lakes-St. Lawrence Seaway System. In 1972, the system carried 214 million tons of cargo, including significant percentages of the U.S. waterborne traffic in iron ore, coal, limestone, and gypsum.

The Great Lakes-St. Lawrence Seaway System is a network of navigable waters composed of the St. Lawrence River, five vast lakes, and their connecting channels as shown in Figure 80, and consisting of some 95,000 square miles of waterway. The system extends from Montreal, the present inland limit of year-round navigation, to Duluth, the furthest inland port on Lake Superior, a water route of 1,344 miles. The system includes Lakes Superior, Michigan, Huron, Erie, and Ontario; their connecting channels; and the St. Lawrence River. The principal connecting channels in the system are the St. Marys River between Lakes Superior and Huron, the Straits of Mackinac between Lakes Michigan and Huron, the St. Clair River-Lake St. Clair-Detroit River System between Lakes Huron and Erie, and the Welland Canal between Lakes Erie and Ontario.

There are locks in three sections of the system, the St. Marys River, the Welland Canal, and the St. Lawrence River. The locks provide a total lift of almost 580 feet. The maximum size of any vessel permitted by the largest of the five parallel locks in the St. Marys River is 1,000 feet long and 105 feet in width. The limiting vessel size for the locks in the Welland Canal and St. Lawrence River is 730 feet long and 75 feet 6 inches in width.

The channels and about 30 deep-draft harbors in the system have been improved by dredging to maintain a 27-foot controlling depth, allowing transit of vessels drawing up to 25 feet 6 inches. Depth over the sills at all locks is greater than 27 feet.

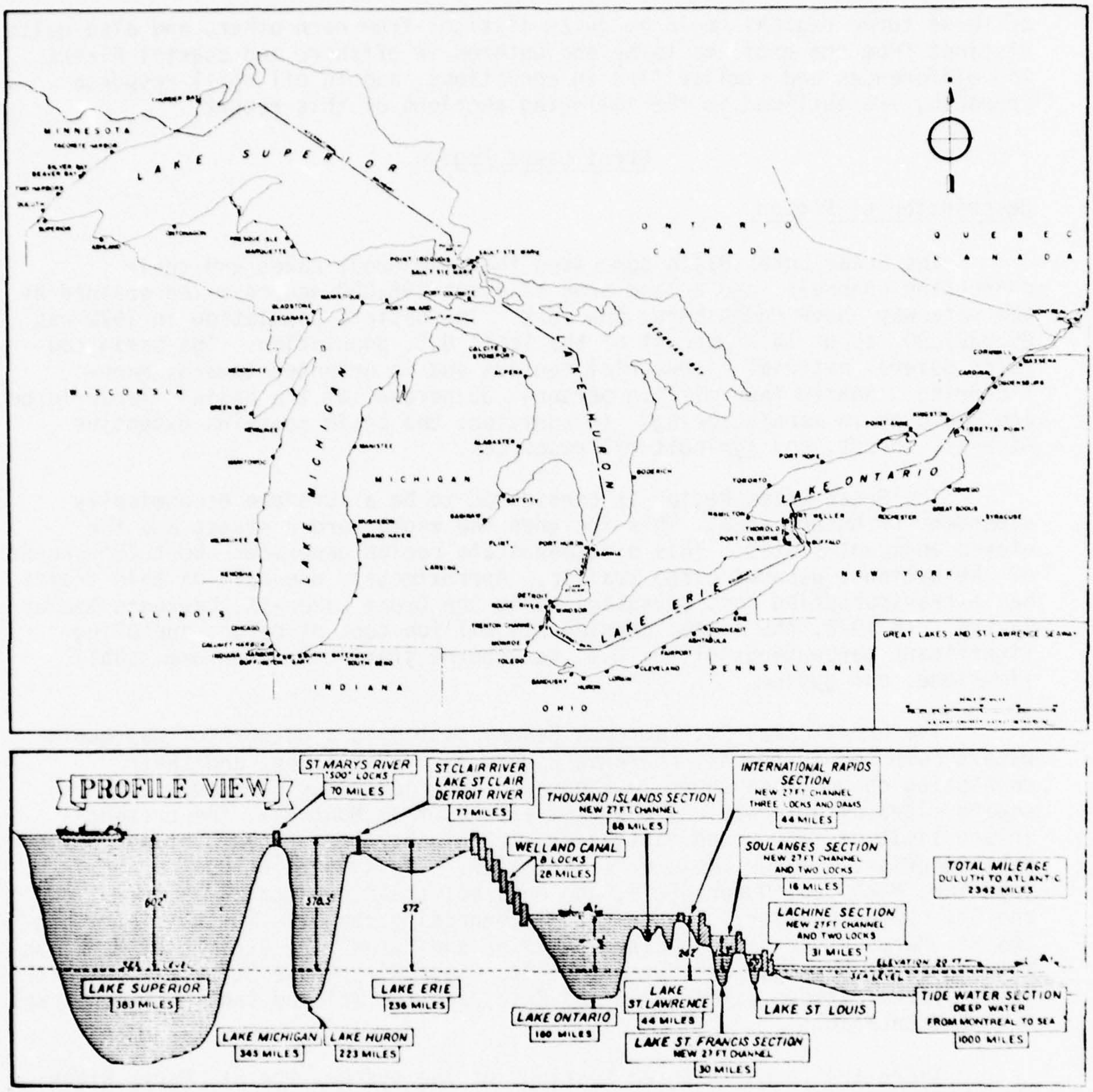


FIGURE 80. THE GREAT LAKES-ST. LAWRENCE SEAWAY SYSTEM

History of Marine Oil Spills

Between January, 1974 and March, 1977 one winter spill and one potential winter spill greater than 50,000 gallons have occurred on the Great Lakes. A tank barge grounding in Lake Michigan resulted in the release of 74,000 gallons of No. 5 fuel oil and a tanker grounding, also in Lake Michigan, presented the potential for spilling 2,300,000 gallons of gasoline.

Marine Traffic

Marine transport of petroleum products on the Great Lakes is almost exclusively performed with self-propelled tankers rather than barges. Residual fuel oils account for 42% of all petroleum traffic, and distillates account for 33%.

Table 57 presents the total tonnages of all products shipped on the lakes and interconnecting waterways in 1976, and Table 58 presents the yearly totals for petroleum products in the interconnecting waterways. The Welland Canal is not included since it is entirely within Canadian territory. No records are kept on shipments through the Straits of Mackinac.

If winter shipments alone are considered, the St. Marys River has been the most highly trafficed area, carrying 61% of all winter cargo on the lakes in fiscal year 1975, and 59% in fiscal year 1976. Total tonnages of petroleum products shipped through the St. Marys River and the St. Clair - Detroit Rivers in the winter of fiscal year 1976 were 94,906 tons and 143,423 respectively.

Environmental Conditions

Environmental conditions for the Great Lakes are summarized in the following sections under the headings of:

- Ice Conditions
- Air Temperature
- Water Depths
- Water Currents
- Waves
- Water Levels
- Water Temperatures
- Daylight
- Precipitation
- Wind and Storms
- Visibility

Ice Conditions

Prediction of ice conditions on the lakes is difficult due to the effects of winds, currents, and upwelling of bottom water. Table 59 lists the expected percent of lake surface area to become ice covered during mild, normal, and severe winters. Figures 81 through 88 show typical bimonthly ice conditions for a normal winter season.

TABLE 57. TOTAL GREAT LAKES SHIPMENTS BY AREA FOR 1976 (ALL COMMODITIES) [18]

Area	Total Tons
Lake Superior	74, 773, 328
Lake Huron	132, 703, 374
Lake Michigan	111, 712, 815
Lake Erie	129, 838, 911
Lake Ontario	45, 706, 954
St. Marys River	78, 930, 737
St. Clair River	96, 360, 190
Detroit River	104, 551, 813
Welland Canal	45, 129, 616

TABLE 58. MARINE TRANSPORT OF PETROLEUM PRODUCTS ON THE INTERCONNECTING WATERWAYS OF THE GREAT LAKES IN 1976 [18]

Area	Vessel Trips (One Way)	Product	Tons/Year
St. Marys River	101 Tankers	Gasoline	87,911
	11 Tank Barges	Distillate Fuels	208,716
	Total All Vessels - 51,866	Residual Fuels	70,224
St. Clair River	89 Tankers	Gasoline	115,093
	10 Tank Barges	Kerosene	5,651
	Total All Vessels - 67,468	Distillate Fuels	138,533
		Residual Fuels	134,569
Detroit River	203 Tankers	Gasoline	87,123
	1,152 Tank Barges	Kerosene	5,651
	Total All Vessels - 16,154	Distillate Fuels	815,507
		Residual Fuels	496,424

TABLE 59. EXPECTED PERCENTAGE OF LAKE SURFACE AREA TO BECOME ICE COVERED [19]

	WINTER TYPE		
	Mild	Normal	Severe
LAKE SUPERIOR	40	60	95
LAKE MICHIGAN	10	40	80
LAKE HURON	40	60	80
LAKE ERIE	50	95-100	100
LAKE ONTARIO	8	15	25

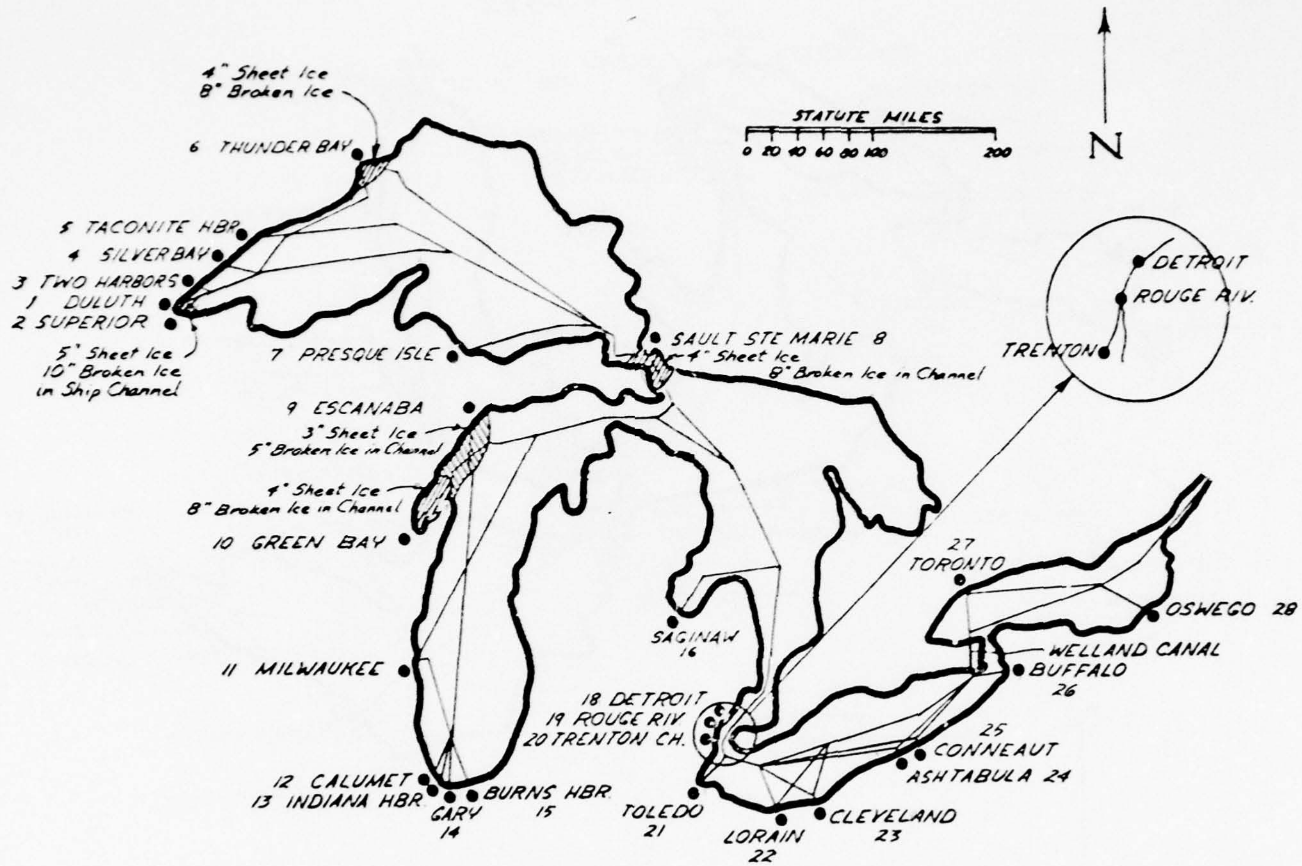


FIGURE 81. GREAT LAKES ICE CONDITIONS FOR NORMAL WINTER (DECEMBER 15-31)

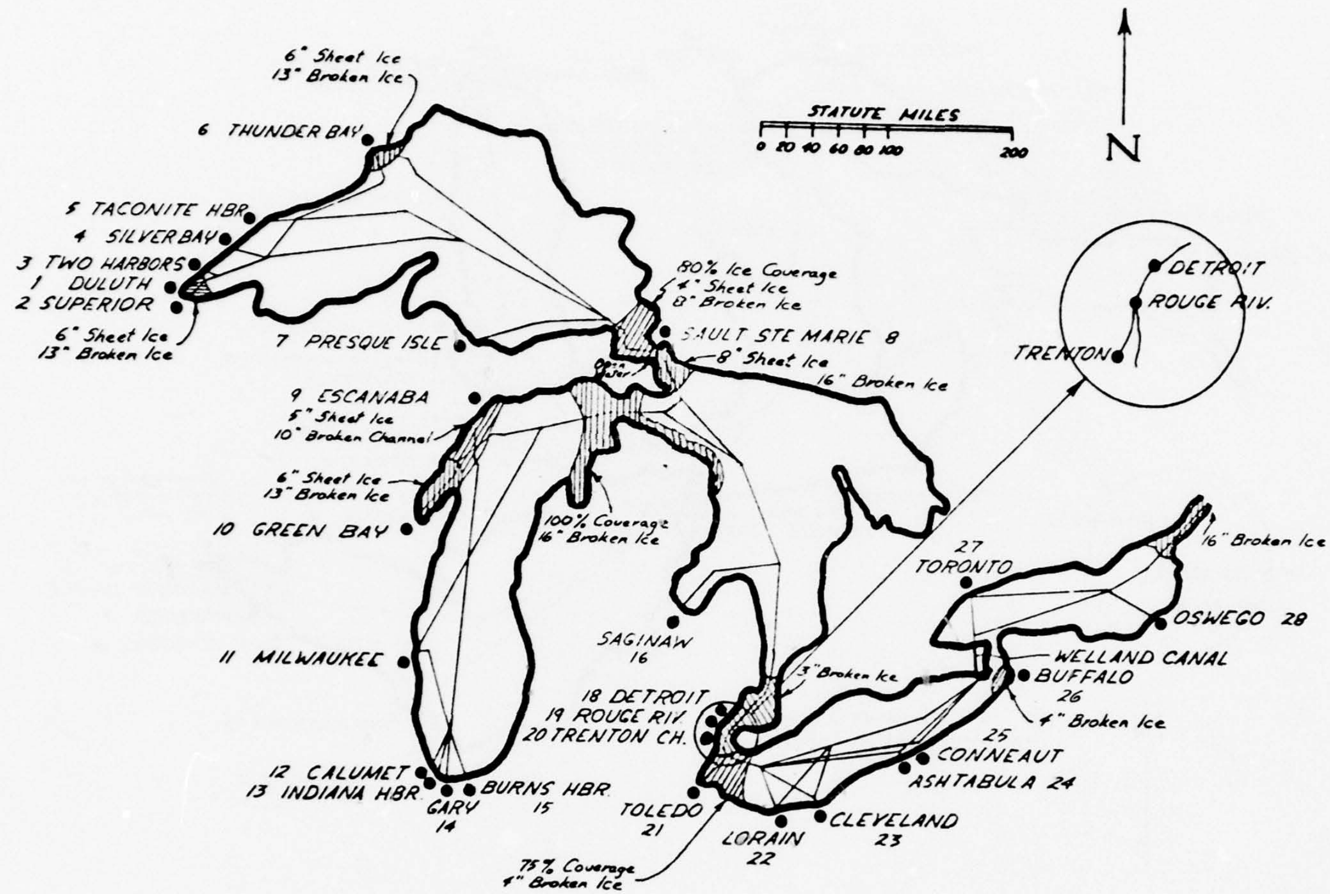


FIGURE 82. GREAT LAKES ICE CONDITIONS FOR NORMAL WINTER (JANUARY 1-15)

THIS PAGE IS BEST QUALITY PRACTICABLE
FROM COPY FURNISHED TO DDC

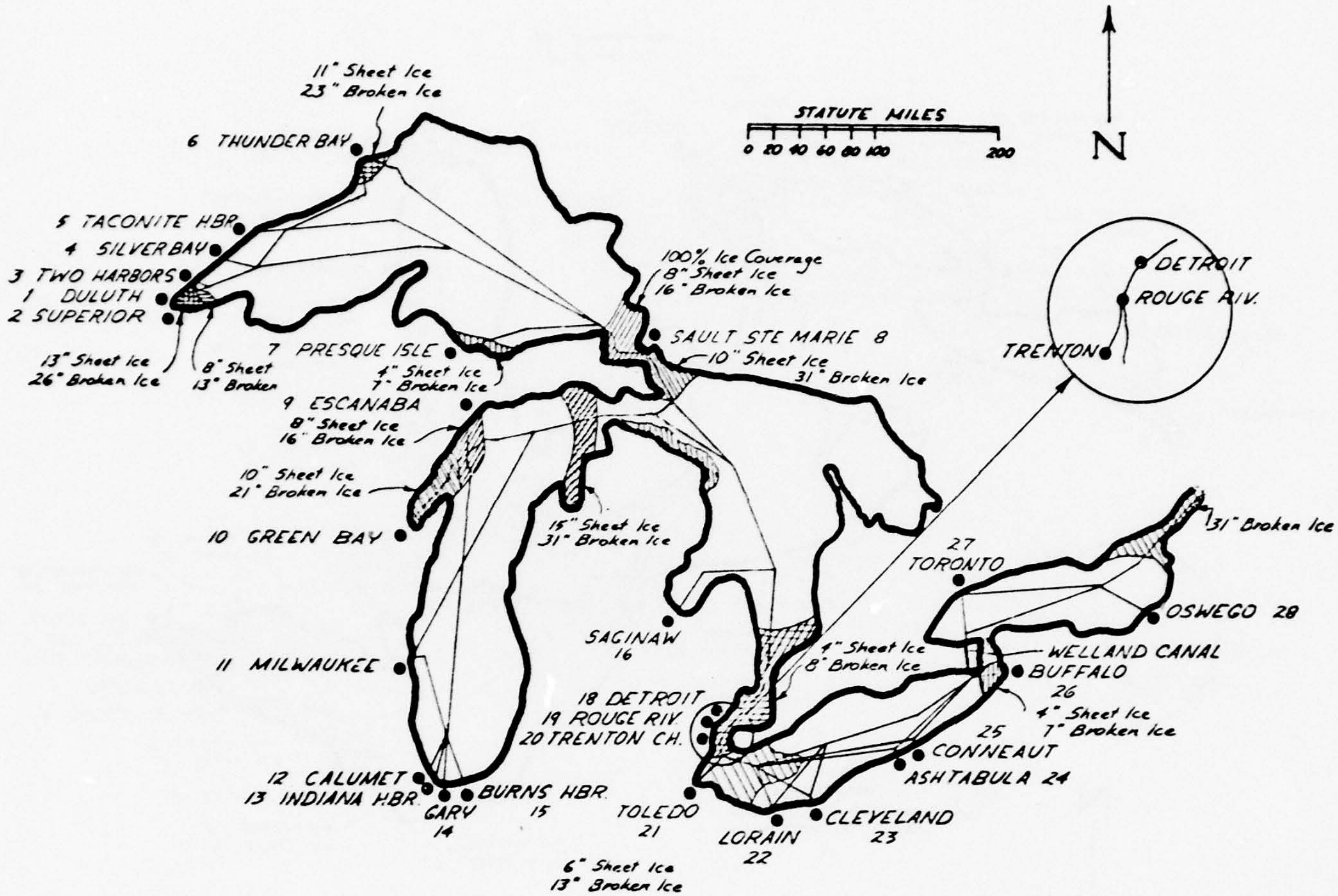


FIGURE 83. GREAT LAKES ICE CONDITIONS FOR NORMAL WINTER (JANUARY 16-31)

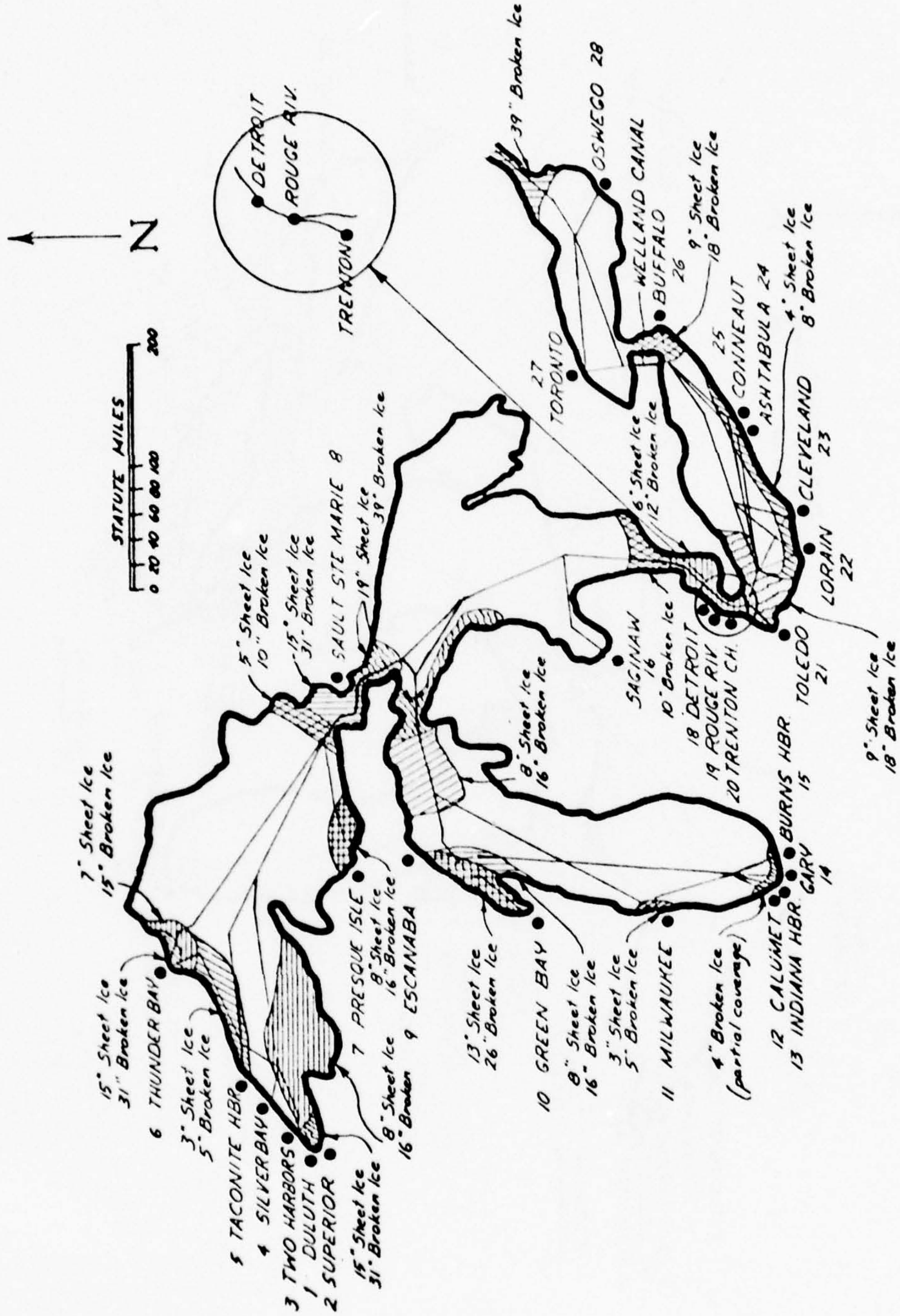


FIGURE 84. GREAT LAKES ICE CONDITIONS FOR NORMAL WINTER (FEBRUARY 1-15)

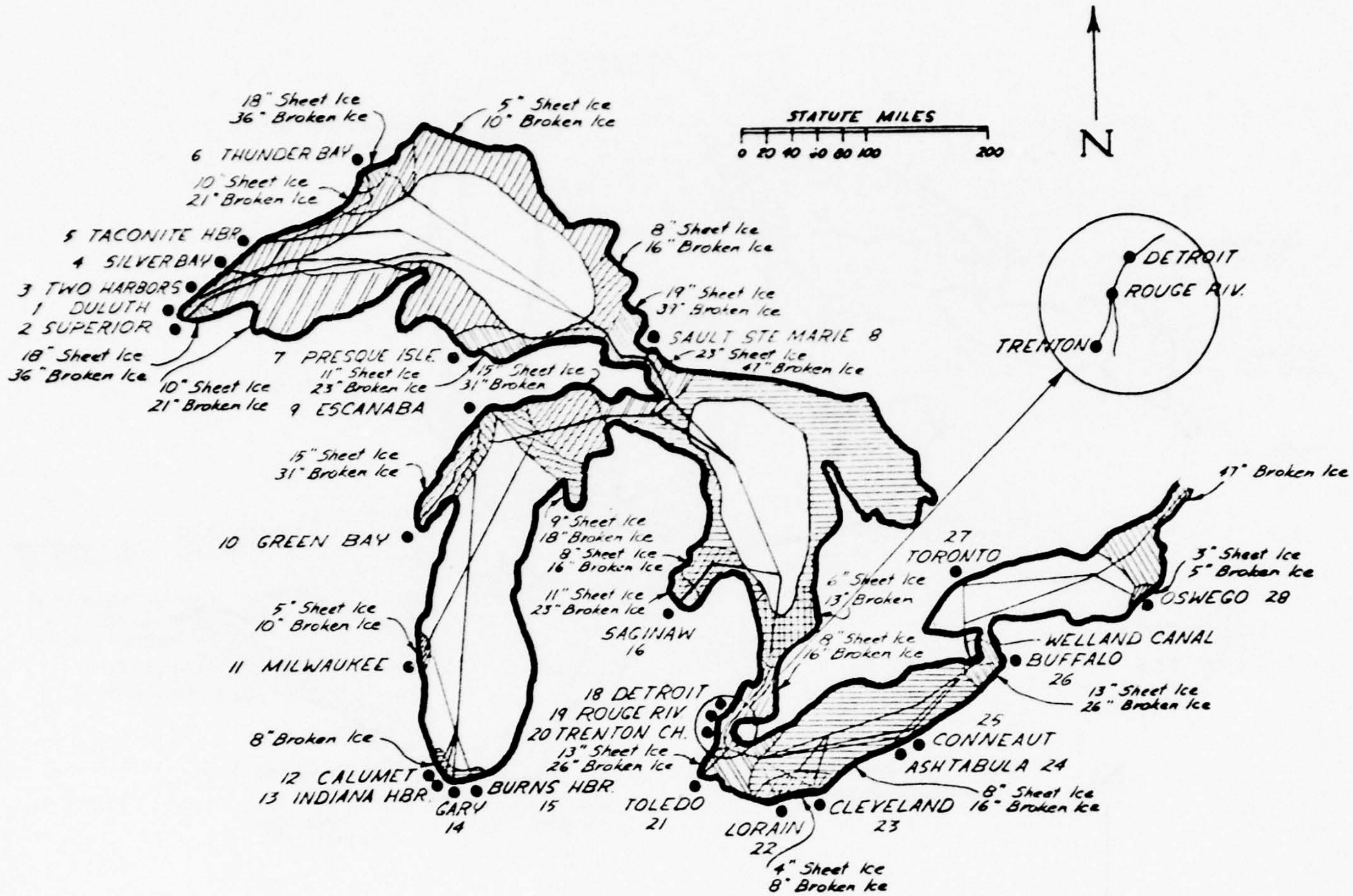


FIGURE 85. GREAT LAKES ICE CONDITIONS FOR NORMAL WINTER (FEBRUARY 16-28)

THIS PAGE IS BEST QUALITY PRACTICABLE
FROM COPY FURNISHED TO DDC

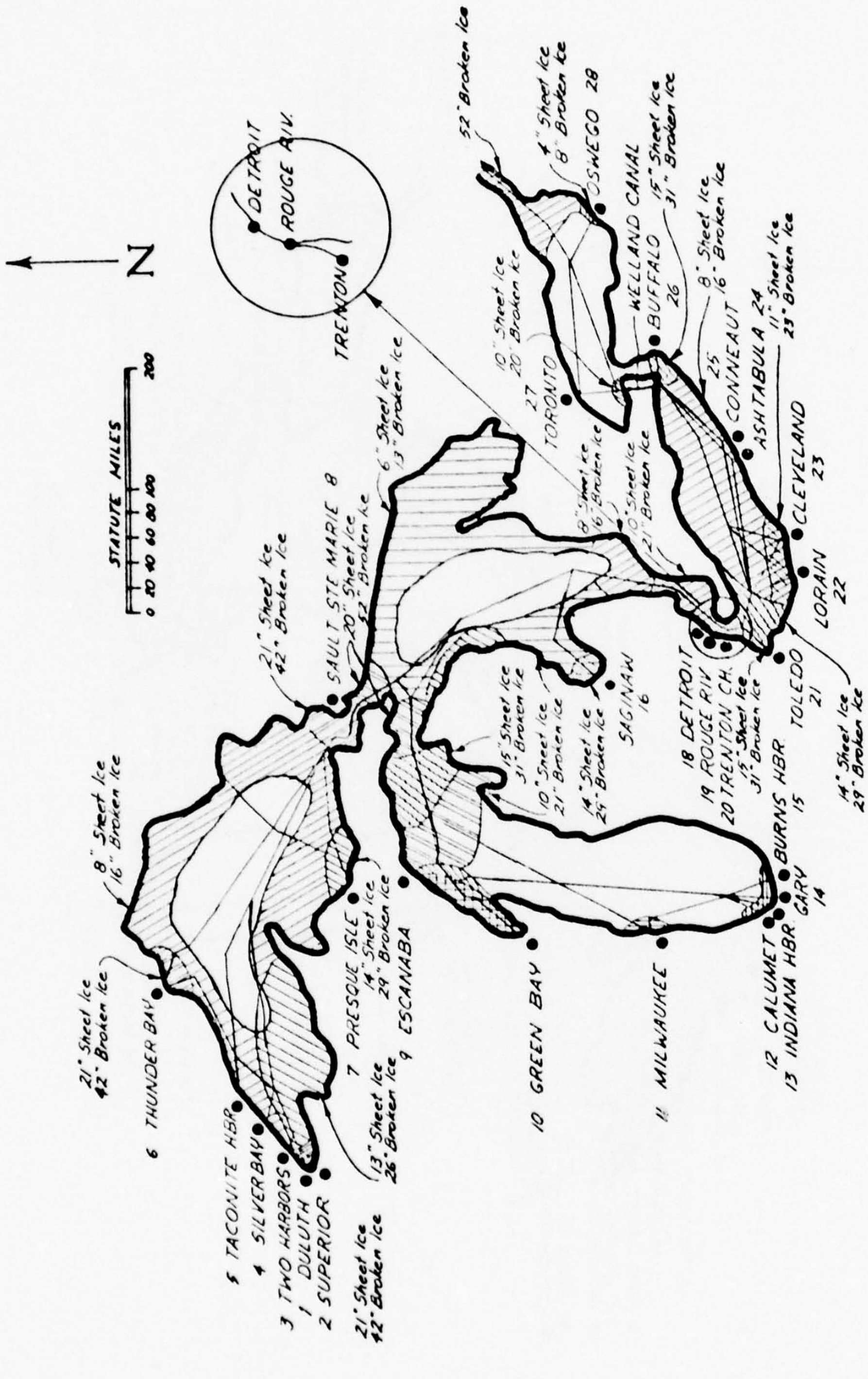


FIGURE 36. GREAT LAKES ICE CONDITIONS FOR NORMAL WINTER (MARCH 1-15)

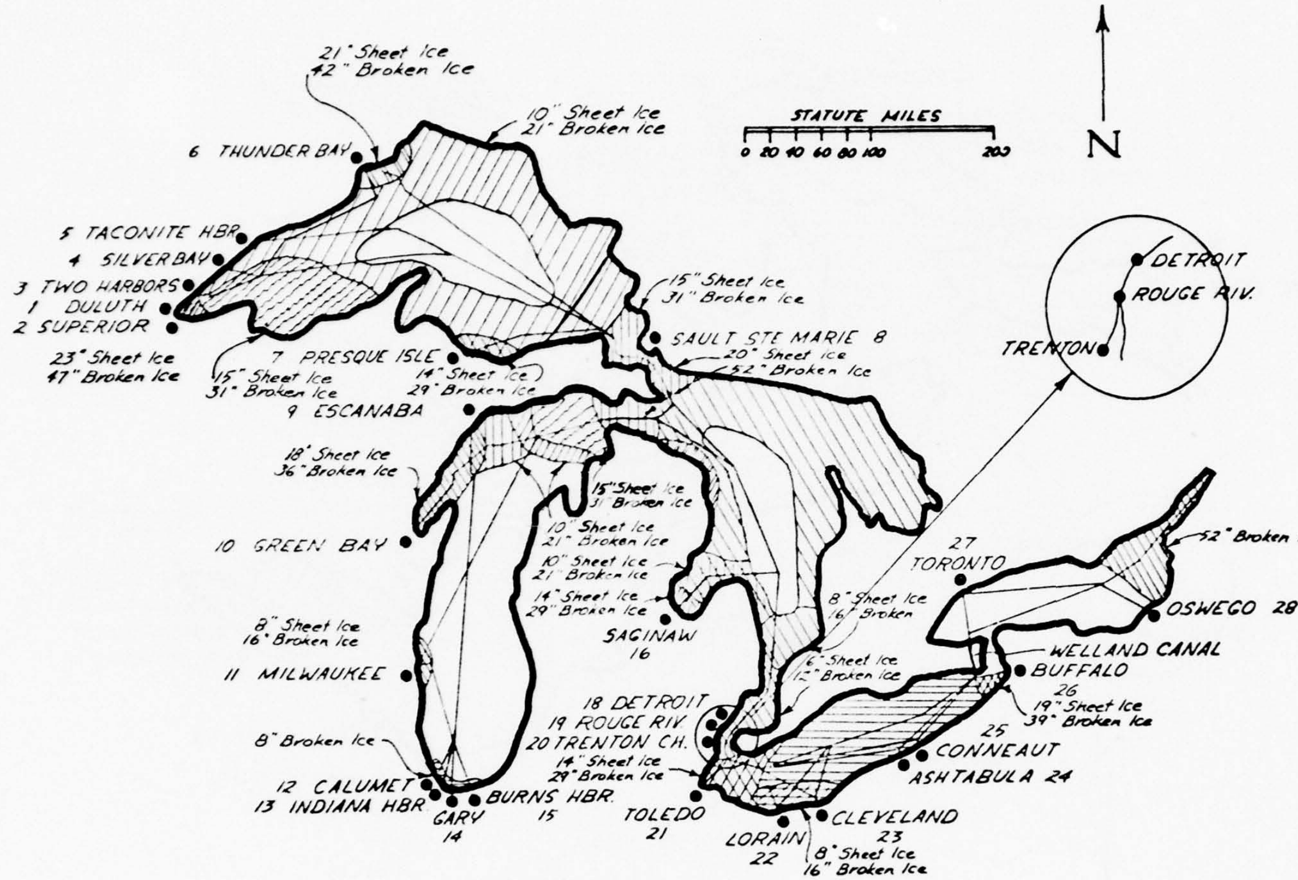


FIGURE 87. GREAT LAKES ICE CONDITIONS FOR NORMAL WINTER (MARCH 16-31)

THIS PAGE IS BEST QUALITY PRACTICABLE
FROM COPY FURNISHED TO DDC

ICE CONDITIONS FOR NORMAL WINTER

(APRIL 1-15)

FIGURE 88. GREAT LAKES ICE CONDITIONS FOR NORMAL WINTER (APRIL 1-15)

Air Temperatures

A noticeable difference in air temperatures over the lakes and over land areas exists because the lakes act as heat reservoirs. This temperature difference is a principal cause of fog and also has some effect on winds and waves. In winter and early spring the lake water temperatures are generally warmer than the air temperature and the result is that the over-lake air temperature is warmer than the air temperature over land areas. From spring to early fall the lake water temperatures are generally cooler than the air temperature with the result that the over-lake air temperature is cooler than the air temperature over land areas. Table 60 shows the mean air temperature of key locations on the Great Lakes.

Water Depths

Water depths of the Great Lakes will not have adverse effects on oil recovery operations. Shallow water can be expected along certain coastal areas and in connecting waterways between the lakes.

Water Currents

Currents in the Great Lakes are principally wind driven. Secondary phenomena that effect the horizontal currents of the lakes are the rotation of the earth, density differences, the shape of the lake basin, water depths and flow-through.

Figure 89 shows the general current patterns on the lakes. The velocity of the currents vary from 0.2 to 0.4 knots. Over short distances, higher speeds might be considered. These may have speeds of approximately 1 knot.

The swiftest currents occur on the navigable connecting channels of the Great Lakes. For the St. Marys River the swiftest currents are found at the Middle Neebish Dike, the West Neebish Rock Cut, and the Little Rapids Cut. The strength of the current depends largely upon the discharge of the river and the elevation of the water surface at the mouth of the river. The discharge of the river is varied according to water-level requirements.

The following limits of velocity may be expected [21]:

Location	Velocity in miles per hour		
	Usual	Probable low	Probable high
West Neebish Rock Cut	2	1-1/4	3-1/2
Middle Neebish (course 6)	1-1/2	1	3
Little Rapids Cut	1-1/2	1	3
Michigan Power Canal	2-1/2	2	3
Ontario Power Canal	2	1	3

TABLE 60. MEAN AIR TEMPERATURES FOR GREAT LAKE LOCATIONS [20]

Location	Monthly Mean Temperature (°F) Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Duluth, Minn.	9.6	12.8	24.1	38.4	48.6	58.0	65.4	64.2	56.0	45.0	29.1	16.1
Sault Ste. Marie, Mich.	14.9	16.2	24.1	38.0	48.7	58.4	63.6	63.6	55.1	46.1	32.9	20.2
Thunder Bay, Ontario	5.4	8.6	20.9	36.3	46.9	56.9	63.5	61.7	52.4	42.9	27.5	12.6
Green Bay, Wisc.	15.7	18.7	26.7	43.0	54.2	64.1	68.6	67.5	58.4	48.5	32.2	21.5
Chicago, Ill.	26.8	28.6	37.6	48.3	58.6	68.9	74.8	73.8	66.8	55.8	41.7	30.6
Detroit, Mich.	26.1	26.6	35.0	47.1	58.3	68.8	73.6	72.1	64.2	53.6	40.4	29.6
Cleveland, Ohio	28.7	29.3	36.5	48.3	59.6	69.7	73.9	72.3	65.5	54.6	41.7	31.2
Buffalo, New York	26.1	27.0	33.8	46.0	56.0	66.4	71.3	70.0	62.6	52.8	40.8	29.2

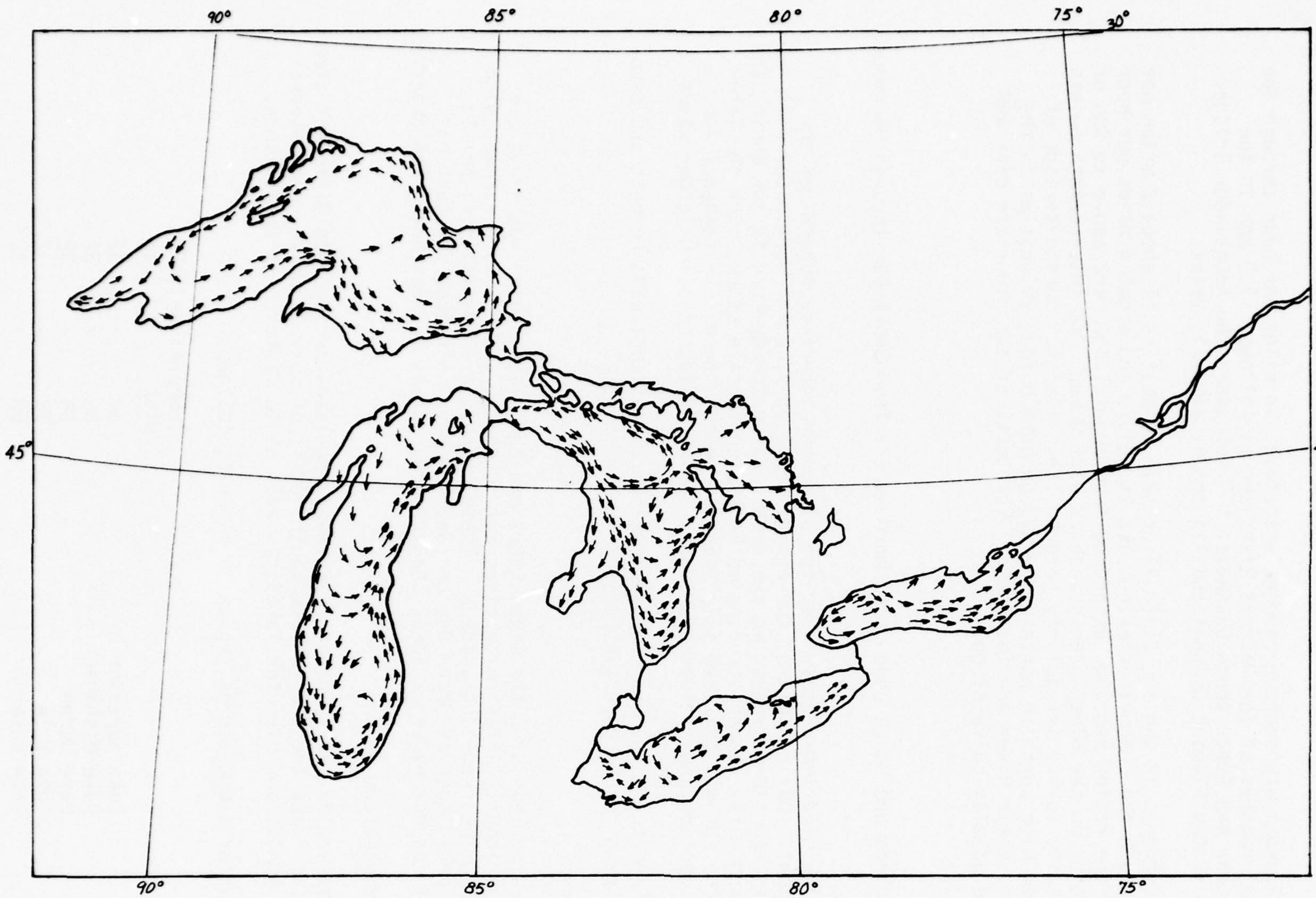


Figure 89. Directions of Mean Great Lakes Currents During the Navigation Season. [20]

Approximate average current velocities in miles per hour through the different reaches of the Detroit River are as follows: 1.9 mph in the Livingstone and Amherstburg Channels; 1.8 mph under the Ambassador Bridge; 1.4 mph in the Fleming Channel and 1.4 mph at Windmill Point.

Currents in the St. Clair River have velocities of about 2 miles per hour through the channel entering Lake St. Clair and about 4 miles per hour through the rapids section, extending from about 1,000 feet above to 200 or 300 feet below the Blue Water Bridge at Port Huron. At intermediate points the velocity varies irregularly between these limits. During periods of sustained high north to northeast winds on Lake Huron, velocities in the upper St. Clair River are increased. The banks of the river are clay and sand and usually quite steep.

Waves

Winds and waves tend to be more severe from September through December.

The wind immediately over the air-water interface determines the wave height. During autumn, the energy released from the warm water will intensify the storm systems in the area. Water temperature is low during the spring and early summer, tending to weaken convective storms over the lakes. During the autumn, the lake is a heat source and there is a tendency for cyclone centers and active cold fronts to intensify, creating larger waves.

Figures 90 through 93 show maximum significant wave heights and probabilities of occurrence synthesized from wind data.

Water Levels

Water levels on the Great Lakes and their associated waterways are not significantly affected by tides but do change due to storm surges, wind set-up and the resulting seiches. These changes are most significant in shallow areas such as Green Bay and Saginaw Bay. Although fluctuations generally do not exceed 2 feet, changes as great as 10 feet have been observed.

Water Temperature

Variations in temperature between the lakes and between different areas in the same lake are due to lake depth, drift of surface water, and meteorological conditions over the lakes, as well as to differences in latitude.

Water temperatures typically range as follows:

	Temperature (°F) High		Low
Lake Superior	54	-	32
Lake Michigan	69	-	32
Lake Huron	64	-	32
Lake Erie	72	-	32
Lake Ontario	68	-	32

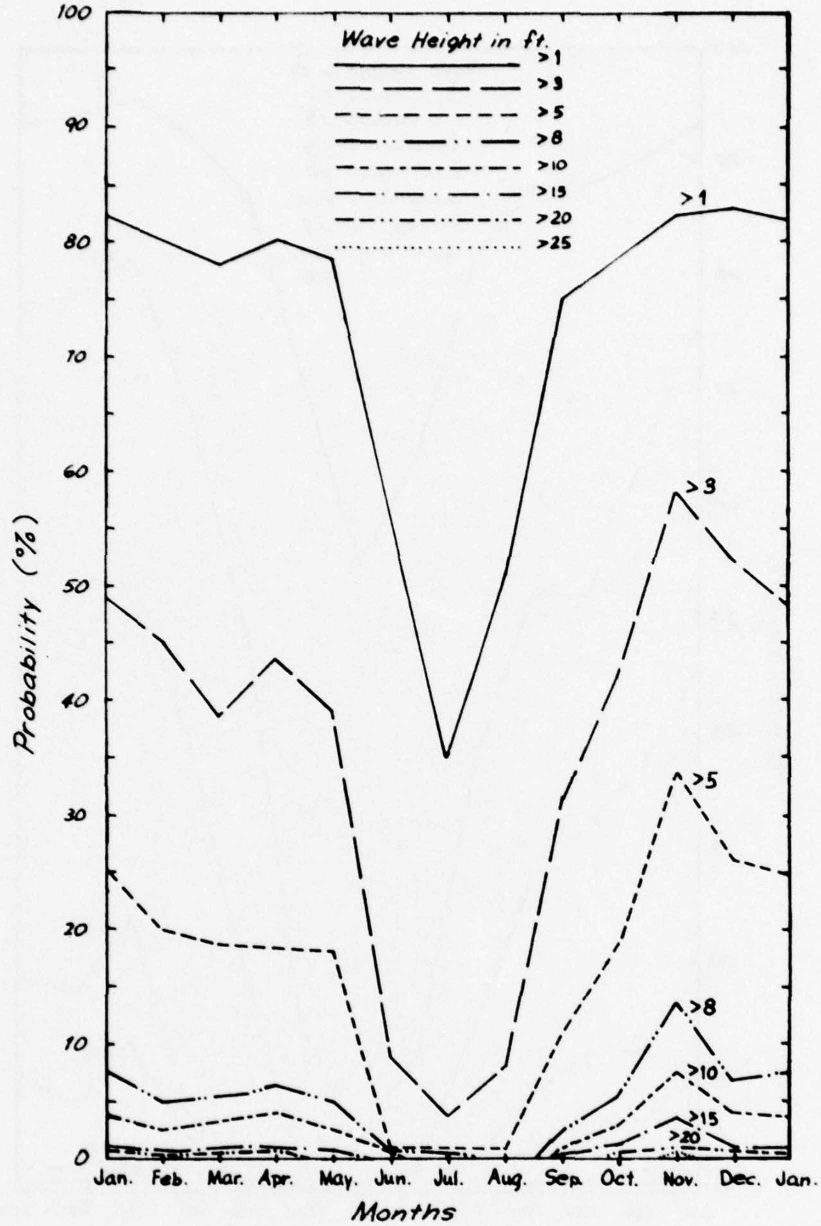


Figure 90. Probability of Significant Wave Heights Greater Than Indicated Thresholds for Lake Superior. [20]

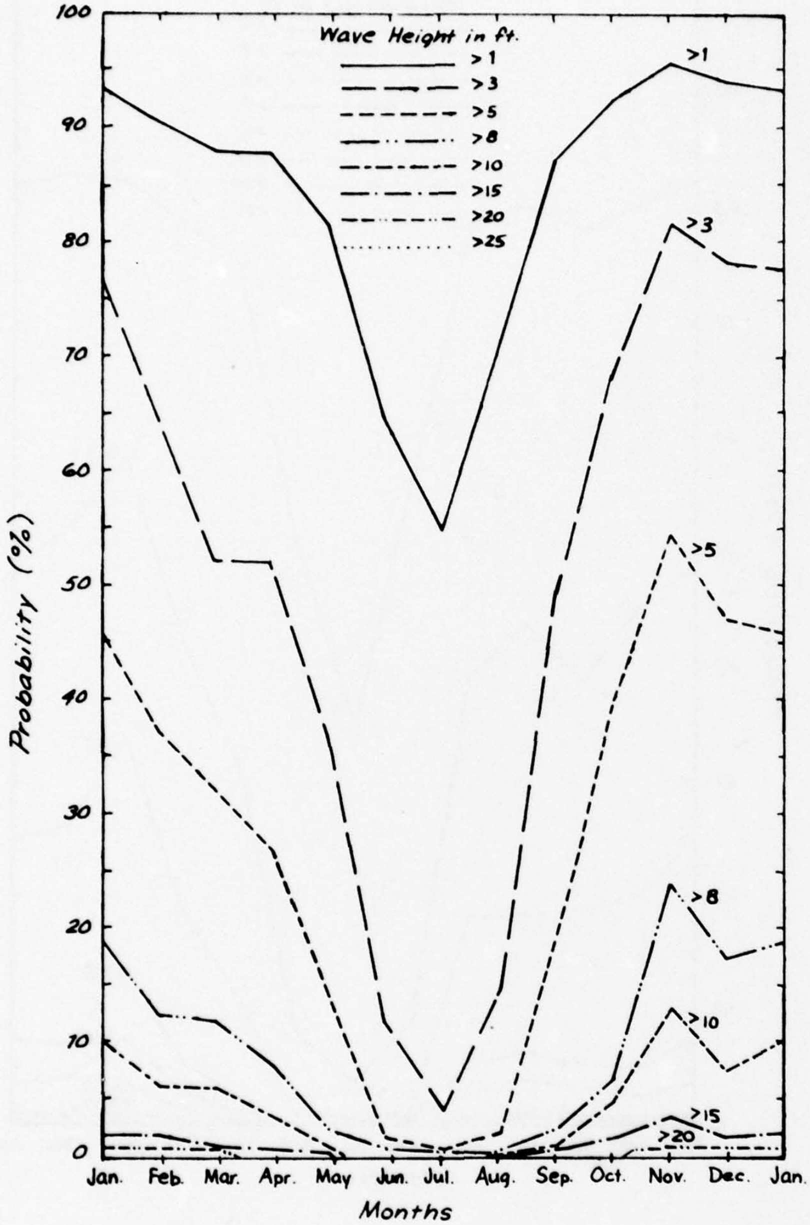


Figure 91. Probability of Significant Wave Heights Greater Than Indicated Thresholds for Lake Huron. [20]

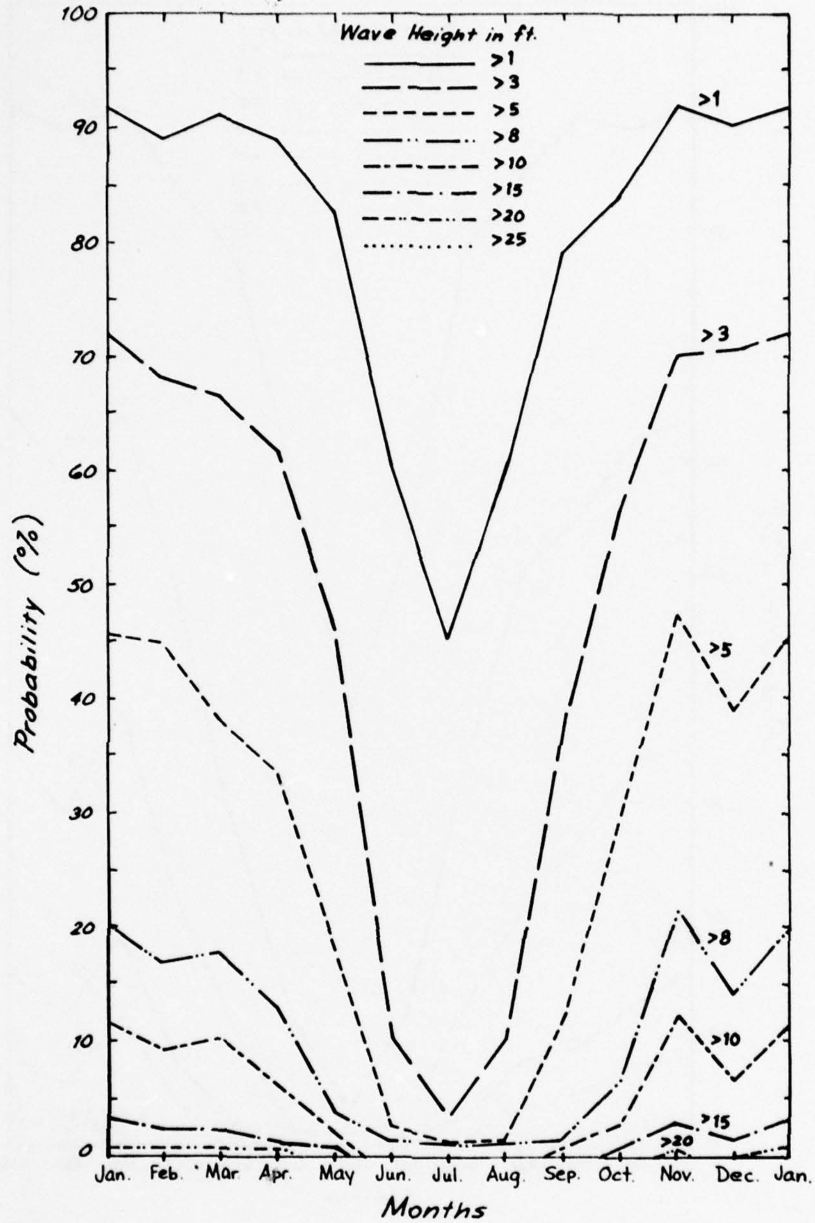


Figure 92. Probability of Significant Wave Heights Greater Than Indicated Thresholds for Lake Erie. [20]

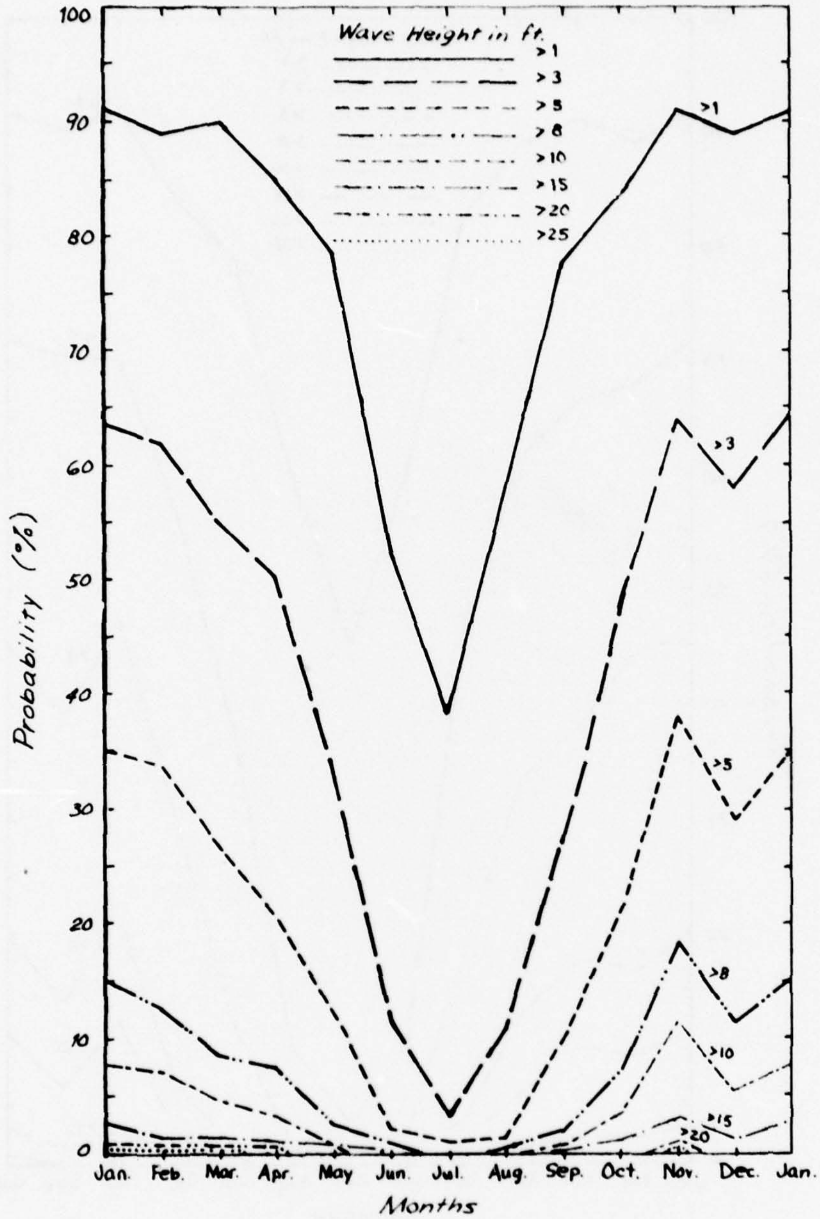


Figure 93. Probability of Significant Wave Heights Greater Than Indicated Thresholds for Lake Ontario.[20]

The direction of prevailing winds affects the lake surface temperatures because winds result in drift of the warmer surface water. These drifts, or surface currents, cause convergence and sinking in the warmer areas, with compensating upwelling elsewhere. In the area of upwelling, the surface water is relatively cold during the warming and early cooling seasons, or until the surface water has been cooled to the temperature of the lower water.

Temperature variations, both within a single lake and between lakes, are greater during the warm months than during the cold months. When the prevailing temperature of a lake is between 32 and 50°F, there is little difference in water densities and mixing extends to the bottom of the lake. This results in little day-to-day variation in temperature.

During the warmer months, there is generally a fairly well-defined thermocline in the lakes. The maximum depth of the thermocline does not exceed 50 feet, although the temperature gradient through it may be relatively steep. The warm surface layer may, at times, be entirely removed by wind, atmospheric pressure variations, or seiches. This allows upwelling of the deeper, colder water and results in little temperature variation from the surface to the bottom water.

Daylight

The following table shows the approximate number of daylight hours at selected locations on the Great Lakes [20]:

	Daylight Hours			
	January	April	July	October
Northern Limit of Lake Superior	8.2	12.2	15.9	12.2
Southern Limit of Lake Erie	9.2	12.2	14.9	12.1

Precipitation

Annual precipitation totals in the Great Lakes region increase from west to east and from south to north. The Gulf of Mexico and the Atlantic Ocean are the chief sources of water vapor for the Great Lakes weather system. Table 61 lists the mean monthly precipitation for the lake basins. The mean annual snowfall for the region and the mean duration of snow cover are summarized in Figures 94 and 95, respectively.

TABLE 61. MEAN MONTHLY PRECIPITATION IN INCHES FOR SELECTED MONTHS FOR THE GREAT LAKES BASINS [22]

	January	April	July	October	Annual
LAKE ONTARIO	2.17	2.63	3.10	2.93	34.5
LAKE ERIE	2.54	3.14	3.06	2.64	33.8
LAKE HURON	2.40	2.43	2.78	2.87	32.0
LAKE MICHIGAN	1.81	2.70	2.99	2.57	31.5
LAKE SUPERIOR	2.06	2.18	3.08	2.55	30.9

Wind and Storms

Table 62 lists the highest observed wind speeds at stations on or near the lakes. Winds are generally strongest in early spring with mean speeds from all directions over 8 miles per hour. Mean wind speeds are listed in Table 63.

In winter, winds tend to have a westerly component. In January, winds blow from the west and northwest 40 to 50% of the time over the middle and upper lake regions. Northwest winds prevail.

November is usually the month of the most frequent severe weather during the season.

The cyclonic storms that effect the Great Lakes are produced by the interaction of the polar and tropical air masses and the general westerly wind circulation.

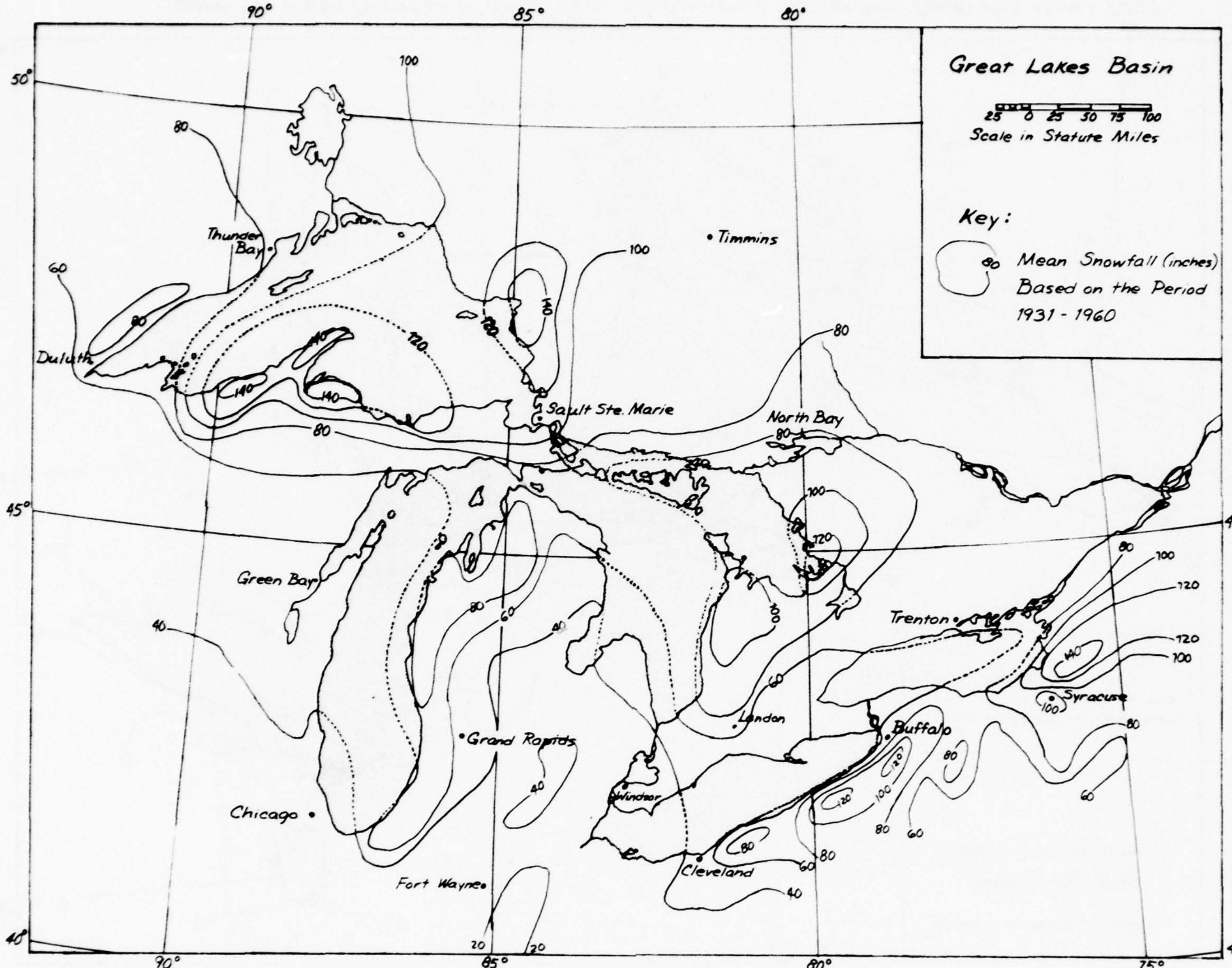


Figure 94. Mean Annual Snowfall. [22]

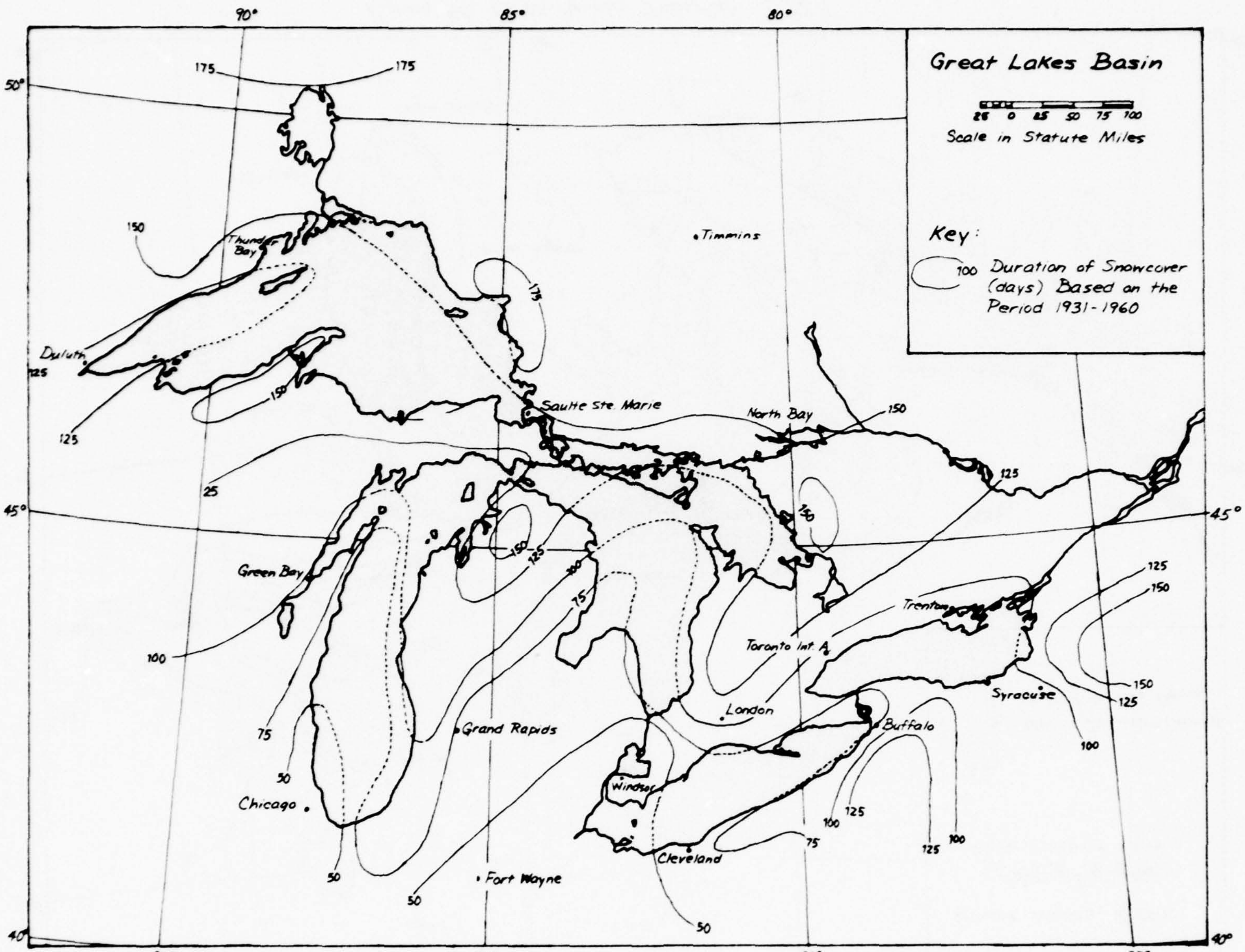


Figure 95. Mean Duration of Snow Cover (Consecutive Days of Snow Depth 1" or More) [22]

TABLE 62. HIGHEST OBSERVED WIND SPEEDS BY MONTH AT LAND STATIONS IN THE VICINITY OF THE GREAT LAKES [30]

Station	Years of Observation	Maximum Wind Speed (mph) Direction of wind											
		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Duluth, Minn	35	65 NW	65 E	75 NW	75 NE	61 W	59 NW	72 W	68 W	60 NW	61 S	68 E	72 NW
Green Bay, Wisc	49	61 W	66 W	68 W	57 NE	109 SW	73 SW	70 NE	56 SW	66 W	66 SW	67 W	61 SW
Chicago, Ill	90	58 NE	87 NE	76 NE	69 SW	69 SW	62 NW	69 SW	62 SW	69 SW	62 SW	76 SE	66 SW
S. Ste. Marie, Mich	71	50 NW	72 NW	60 SE	72 SW	49 SE	54 W	56 W	56 SW	62 SW	62 W	66 W	58 NW
Detroit, Mich	28	57	49	68	56	61	56	77	50	52	56	66	59
Cleveland, Ohio	31	71 W	65 SW	74 W	65 NW	78 SW	68 NW	66 W	61 W	56 S	68 W	57 SW	59 W
Buffalo, New York	50	91 SW	73 SW	84 SW	73 W	63 SW	73 W	62 SW	60 W	68 SW	71 W	76 SW	85 SW
Thunder Bay, Ontario		40 N	34 NW	37 NE	41 NW	39 NW	39 W	38 W	34 NW	38 W	42 W	45 NW	42 NW

TABLE 63. MEAN MONTHLY WIND SPEEDS FOR LAND STATIONS IN THE VICINITY OF THE GREAT LAKES [20]

Station	Mean Wind Speed (mph)												
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Average
Duluth, Minnesota	12.2	12.2	12.2	13.6	12.7	11.0	10.0	9.9	10.9	11.7	12.4	11.7	11.7
Thunder Bay, Ontario	9.5	9.3	10.0	10.4	9.7	8.9	8.3	7.8	8.6	9.2	9.6	9.5	9.2
Green Bay, Wisconsin	10.6	10.1	11.6	11.8	11.0	9.7	8.2	7.5	9.4	9.9	12.0	11.0	10.2
Chicago, Illinois	11.4	11.6	11.8	11.7	10.4	9.2	8.2	8.0	8.9	9.8	11.4	11.2	10.3
S. St. Marie, Michigan	10.2	10.2	10.5	10.9	10.4	9.0	8.4	8.3	9.1	9.7	10.4	10.2	9.8
Detroit, Michigan	11.5	11.5	11.4	11.1	9.8	9.0	8.2	8.0	8.8	9.5	11.4	11.3	10.1
Buffalo, New York	14.4	14.2	13.9	13.1	12.0	11.4	10.7	10.2	10.7	11.5	13.1	13.6	12.4

Visibility

Historical data on visibility at selected Great Lakes sites is summarized as follows in terms of the average number of days per month with visibility less than 1/4 mile due to fog or blowing snow [23]:

MONTH	BUFFALO	DULUTH	ERIE	SAULT STE. MARIE
January	9	8	8	11
February	8	6	7	8
March	7	7	6	7
April	3	5	3	5
May	2	5	2	3
June	1	7	1	4
July	1	5	0	5
August	1	6	0	6
September	1	6	0	6
October	1	5	0	6
November	2	4	1	8
December	1	3	1	12

Selection of Spill Scenario No. 7

On the Great Lakes, several alternative spill scenarios can be developed and evaluated on the basis of both spill potential and environmental severity. The examination of spill potential can be related to the level of marine traffic, water depth, and ease of navigation. The greatest potential for marine casualty is in the connecting waterways between the Great Lakes. This would involve such areas as the St. Marys River, the Mackinac Straits, the St. Clair River, and the Detroit River, to name a few. Having established that the connecting waterways are the areas for greatest probability of a ship casualty due to restricted navigable channels and ice jamming as defined in the previous section, it now becomes necessary to establish which of the connecting waterways should be used for the spill scenario. The St. Marys River has been selected because of the high traffic in the waterway during extended season operation and the severe ice conditions that are present. Although petroleum product traffic on the St. Clair - Detroit River system is greater, ice conditions on the St. Marys River are more severe and the total number of vessels operating in the winter is much greater.

The site selected within the St. Marys River is at Johnson's Point Turn, which is the sharpest turn in the river system, and where all ship maneuvers occur within a dredged channel. For this scenario, it is assumed that a tanker grounding at Johnson's Point Turn occurs in February and 10,000 barrels (420,000 gallons) of No. 6 residual fuel oil are released. The location of the spill is shown in Figure 96.

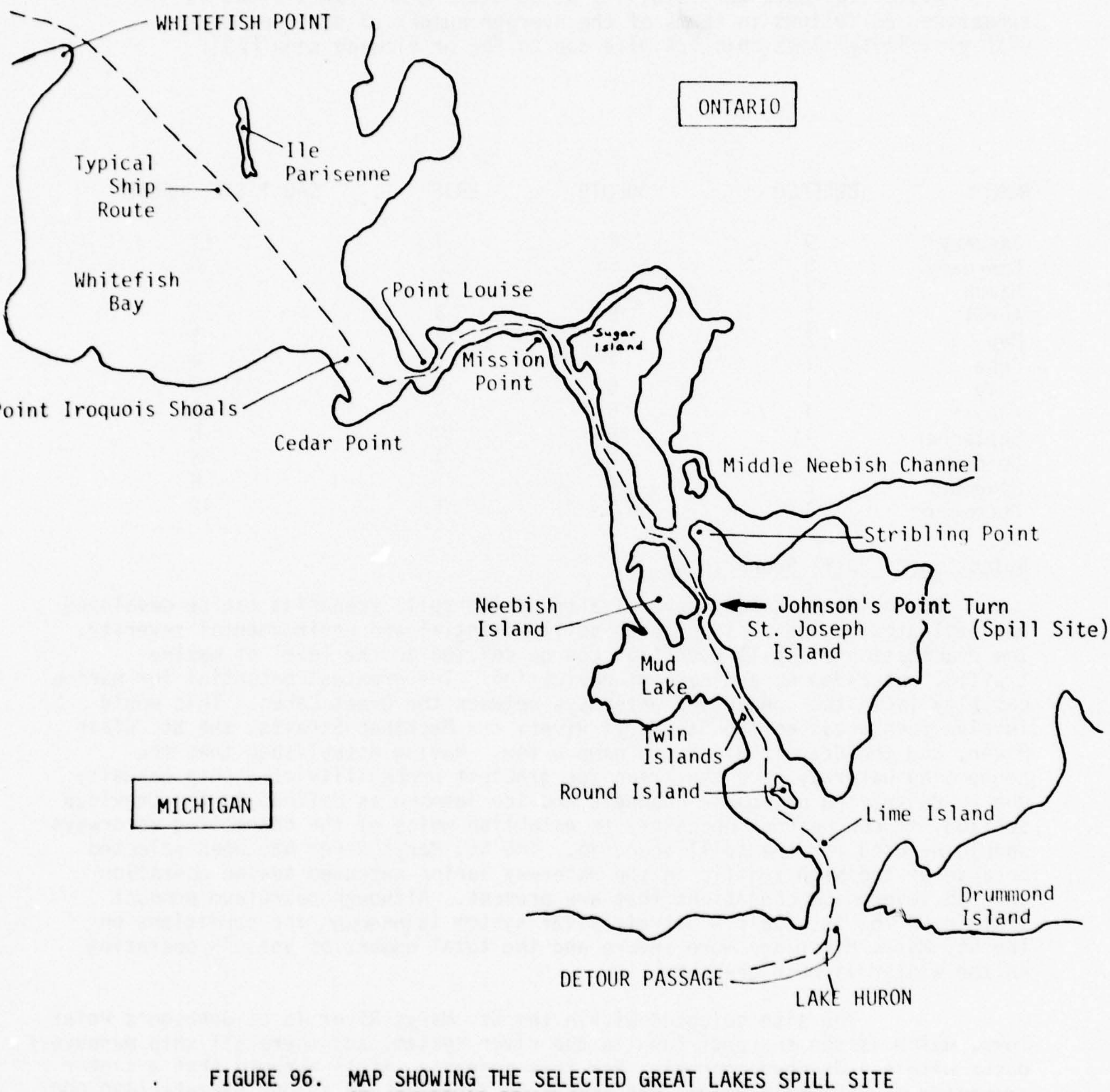


FIGURE 96. MAP SHOWING THE SELECTED GREAT LAKES SPILL SITE AT JOHNSON'S POINT TURN, ST. MARYS RIVER

Spill Mode

The spill mode selected for the Great Lakes oil spill scenario consist of a tanker grounding at Johnson's Point Turn in the St. Marys River resulting in the rupture of three cargo tanks and the instantaneous release of 10,000 barrels of No. 6 residual fuel oil. The tanker grounding is selected to take place in February when the channel is 100% clogged with broken ice contained by level ice outside of the channel.

Spill Environmental Conditions

The ice cover at Johnson's Point Turn in February, March and April is characterized by a broken ice field in the navigation channel, bordered with level shorefast ice outside the channel. Typical thicknesses of the level shorefast ice outside of the navigation channel are 19 inches in early February, increasing to 23 inches by late February, then holding at about 20 inches throughout March, and decreasing to 8 inches by the end of April. The thickness of the broken ice in the navigation channel increases from 39 inches in early February, to 47 inches by the end of February, leveling off at 52 inches in March, and decreasing to 16 inches by the end of April. Mean air temperatures are typically 16°F in February and 24°F in March. Minimum air temperatures will typically be 7°F in February and 16°F in March. The water temperature will be 32°F. The controlling depth of water in the St. Marys River is 28 ft. The average water current at Johnson's Point Turn will be 1 knot.

Visibility at Johnson's Point Turn will typically be reduced to less than 1/4 mile due to fog or blowing snow one to two days in February, and for as much as 1 week in March. There will be at least 8 hours of daily daylight throughout the winter months. Approximately 8 inches of snow can be expected to be on the ground at the time of the spill, with 3 to 6 inches of additional snow falling within one week of the spill. The average monthly snowfall is 19 inches in February and 15 inches in March. Winds will typically be 10 mph from the east in February, and 10 mph from the west-northwest in March. Maximum observed wind speeds have been recorded as 72 mph in February and 60 mph in March. Waves will not be a factor in the area due to the ice cover. February is typically storm-free, and one storm can typically be expected in the month of March.

Spill Behavior

The oil spill scenario is based on the assumption that the tanker grounds at the edge of the channel on the inside of the turn along the west bank. As shown schematically in Figure 97, the one knot current will carry the oil downstream into the channel south of Johnson's Point. Since the specific gravity of No. 6 fuel oil at 32°F is 0.96, the oil will float up into the stationary broken ice in the channel where it will be sheltered from the current and remain in place. A relatively small amount of the oil is expected to be swept under the level ice outside of the navigation channel. This distribution of oil in the rubble ice field of the navigation channel and beneath the adjacent sheet ice is shown schematically in Figure 98.

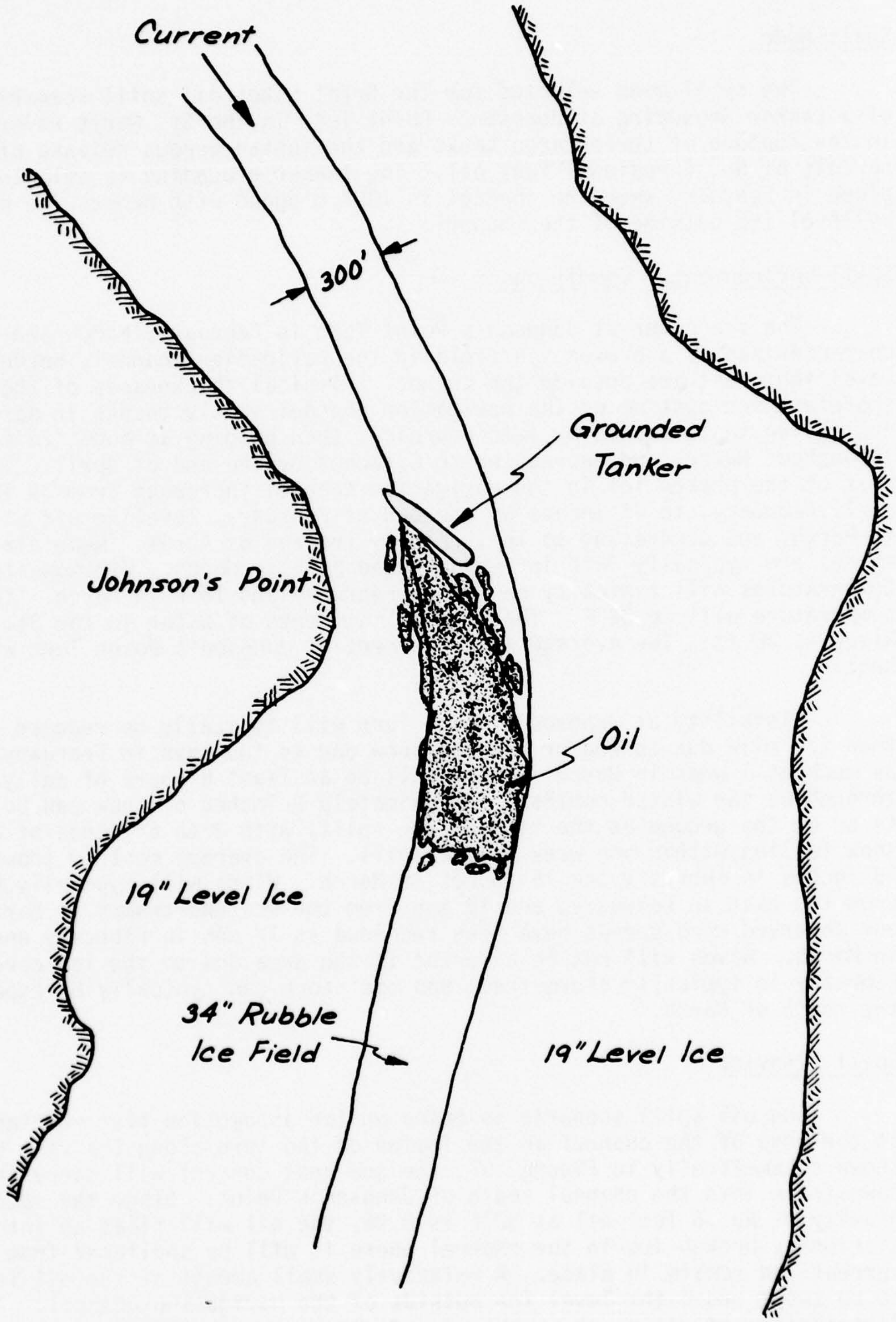


Figure 97. Conceptual Sketch of the Spill of 10,000 bbl of No. 6 Fuel Oil at Johnson's Point Turn

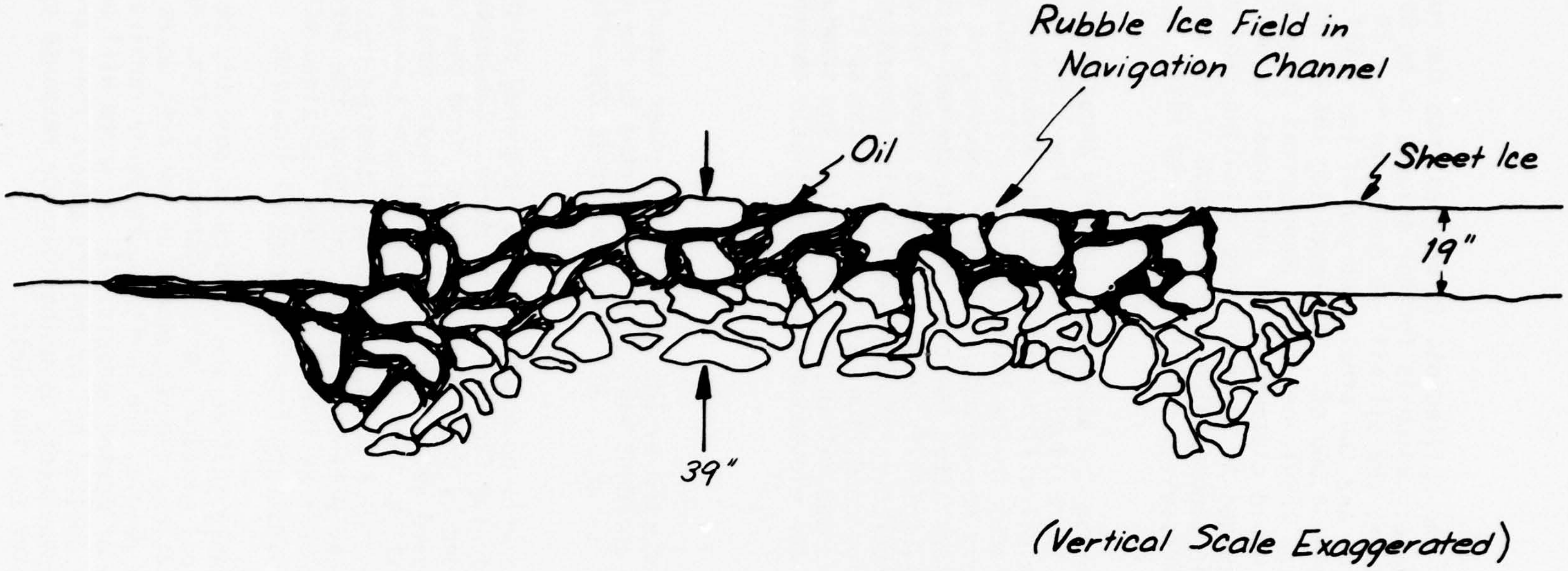


Figure 98. Schematic Representation of the Distribution of the Oil in the Ice Field Shortly After the Johnson's Point Turn Oil Spill.

Assuming that 90% of the spilled oil is carried into the rubble ice field in the navigation channel, which is further assumed to be 50% solid ice pieces and 50% water by volume, the oil will be contained in a 19 inch layer by the surrounding level ice, and the areal coverage of the spill in the channel will be approximately 64,000 sf. The remaining 10% of the spill is assumed to locate beneath the level ice, which when spread to an equilibrium thickness of about 1 inch, would contaminate an additional 63,000 sf of the ice cover. This, however, is judged to be an extreme situation, and unlikely since the oil will probably remain concentrated near the edge of the channel at significantly greater thicknesses, since the oil will solidify as it cools below its pour point of 34°F.

Losses due to weathering are assumed to be only about 5% by the end of two weeks since the oil is residual fuel oil with few light fractions, and since only a portion of the oil will be exposed to the atmosphere at 16°F. Oil penetration into the ice pieces in the broken channel will be minimal since fresh water ice is relatively non-porous. Oil will, however, be frozen in pockets between the ice pieces after the oil comes to thermal equilibrium in the ice field. The oil will solidify in these pockets since its pour point of 34°F is above the water temperature of 32°F and the air temperature of 16°F. Since the ice is in a growing condition at the time of the spill in early February, the oil will be frozen within the ice field. Any snowfall occurring after the spill will cover the exposed oil with very little absorption of oil by the snow.

Spill Response

The spill will be detected by the crew of the tanker immediately after the grounding occurs. The accident will then be reported to the Coast Guard at Sault Ste. Marie by ship's radio. All ship traffic to the affected area will be stopped.

Initial surveillance will be accomplished by the crew of the tanker until Coast Guard vessels arrive from Sault Ste. Marie. Subsequent visual surveillance will be provided by Coast Guard personnel from the Coast Guard vessels and from a Coast Guard helicopter. All significant pools of oil within the affected area will be marked as soon as possible so that they can be located even in the event of a snowfall. It is estimated that one helicopter overflight per day will be required throughout the period of spill response operations to assure that the oil is indeed contained with the broken ice field and not moving downstream from its original location.

While it is conceivable that an ice boom could possibly be used to move the broken ice/solidified oil mixture closer to shore to allow the conduct of a shore-based cleanup operation, the remoteness of the area makes shore-based cleanup impractical. As a result, the preferred response requires a cleanup operation based on the use of marine vessels. Since there will be substantial natural containment of the spilled oil by the ice cover, there are no additional requirements for containment, assuming that the response operation is completed prior to breakup of the ice field.

Since the level ice cover surrounding the navigation channel is not adequate to support heavy vehicles and equipment, and shore-based recovery is not feasible due to the remoteness of the area, all recovery operations must be carried out from marine vessels. The west bank of the river on Neebish Island is only accessible over ice covered dirt roads, and no vehicles heavier than snowmobiles can cross the Oakridge Ice Bridge on the eastern bank of the island. On St. Joseph Island, which forms the east bank of the river, similar road conditions exist. Therefore, over-land transit of recovery equipment and recovered oil and ice will not be possible. The condition of the residual oil and the ice in the navigation channel, along with the low air temperatures, eliminates several recovery options. The successful burning in situ of small pockets of somewhat weathered solidified residual fuel oil is unlikely. Also, since the oil will be at a temperature below its pour point, the use of direct suction devices and pumps is not possible. Conventional oil spill recovery devices will also be ineffective since the oil and ice cannot be readily separated due to the solidification of the oil. The preferred response therefore consists of a system capable of processing large pieces of broken ice and intermixed oil. The physical recovery of the oiled ice is required, followed by processing to separate the oil from the ice. For the 25 and 50% response levels, it has been estimated that recovery could be accomplished through the use of a clam shell or drag line dredge operating with a hopper barge. One crane and nine men would be required for a period of six days to achieve the 25% response level, and twelve days to achieve the 50% response level, with crews working eight hours per day in both cases. An icebreaker would be at the scene to assist in recovery operations. Further increasing the response level to 90% will require that all of the oil in the channel, and some of the oil beneath the adjacent level ice cover, be recovered. It is envisioned that a special oil/ice recovery vessel, similar to the unit proposed in some of the arctic spill response scenarios, would be necessary to achieve this response level. Some type of conveyor recovery mechanism would be necessary so as to eliminate the losses associated with the drain-off from the clam shell or drag line type of recovery operation. A device having this capability does not currently exist.

All temporary storage requirements would have to be met by marine vessels since the use of containers on top of the ice is not feasible, and the remoteness of the area precludes over-land transfer. Because of the large volume required for storage of the recovered oil/ice mixture, hopper barges will be the preferred means for temporary storage. These barges need not be ice strengthened if they are escorted to the spill site by Coast Guard icebreakers. Storage capacities of 2,100 cubic yards, 4,200 cubic yards and 9,500 cubic yards would be required for the 25, 50 and 90% response levels respectively. Since the recovered oil and ice will be deposited directly in the barges and stored in the barges until spring, no further storage facilities will be required.

The response scenario is based upon allowing the oiled ice in the hopper barges to melt naturally as temperatures increase in the spring. Once melting has been completed and the oil is separated from the ice, temperatures will be

such as to allow transfer of the oil from the barges to an onshore disposal site through the use of conventional pumping systems. The stricken tanker will be offloaded to permit its removal from the shoal. A tank barge with a steam generator and an ADAPTS pumping system will be required for offloading the stricken tanker.

The preferred response calls for disposal of the oil to onshore oily waste processing plants after the oil has been separated from the ice by allowing the ice to melt in the hopper barges.

The logistics effort associated with this spill response scenario will be primarily marine based. Coast Guard vessels and personnel will proceed to the spill site from Sault Ste. Marie as soon as the accident is reported to serve as the onscene command and communications center. A helicopter will be made available at the site to assist with surveillance and emergency evacuation as necessary. The barges and the associated equipment required for recovery will be brought to the site from Chicago, with an icebreaker escort arriving onscene about 5 to 7 days after the spill occurs. Accommodations for the spill response team will be provided aboard the vessels responding to the spill.

Weather forecasts will be important for the guidance of the spill response operation. Ice forecasts and an oil spill behavior model will not be necessary since both ice and oil conditions will have stabilized shortly after the spill occurs. Paramedical facilities will be available on the Coast Guard icebreaker, and emergency cases can be flown by helicopter to Sault Ste. Marie.

The preferred spill response techniques determined for the Great Lakes spill scenario at Johnson's Point Turn of the St. Marys River are summarized for the three levels of response capability in Table 64. The equipment required to achieve each response level for this scenario is identified in Tables 65 and 66.

TABLE 64. SUMMARY OF PREFERRED SPILL RESPONSE TECHNIQUES FOR THE GREAT LAKES SPILL SCENARIO

Function	25% Response Level	50% Response Level	90% Response Level
Detection	Visual by crew of grounded tanker	Same	Same
Surveillance	Initially by tanker crew than by Coast Guard personnel from ship and helicopter	Same	Same
Containment	Natural	Same	Same
Recovery	Clam shell or drag line dredge	Same	Special oil/ice recovery vessel
Storage	Hopper barge	Same	Special oil/ice recovery vessel
Transfer	Conventional pumps	Same	Special oil/ice recovery vessel
Disposal	Shore side oily waste processing plant	Same	Special oil/ice recovery vessel
Logistics	Coast Guard vessels from Sault Ste. Marie, barges and tugs from Chicago	Same	Same
Ancillary	Daily weather forecasts	Same	Same
Emergency Evacuation	Paramedical facilities on ice-breaker, helicopter for emergency cases	Same	Same

TABLE 65. EQUIPMENT REQUIRED TO ACHIEVE THE 25% RESPONSE LEVEL FOR SCENARIO NO. 7

Subsystem	Item	No. Req'd.	Specifications	Weight/Volume
Surveillance	Helicopter	1		
	Surface markers	200	Buoyant, disposable	
Containment	None			
Recovery	**Crane barge	1	Clamshell or dragline on 4,000 yd^3 barge	
Storage	Tank barge	1	10,000 bbl with a steam generator and pumps	
Transfer	ADAPTS pumping system	1	1000 gpm @ 32 ft disch.	
Disposal	None			
Logistics	Tugs	2		
	Icebreaker	1	MACKINAW or Wind Class	
	C-130	1		
	Special Clothing	10 sets	Low temperature, oil resistant	
Ancillary	Weather forecasts	daily		
	Communications equipment			
Emergency Evacuation	Helicopter (listed above)	1		

** Demonstration required.

TABLE 66. VARIATIONS IN EQUIPMENT REQUIRED TO ACHIEVE THE 50% AND 90% RESPONSE LEVELS FOR SCENARIO NO. 7

Response Level	Surveillance	Containment	Recovery	Storage	Transfer	Disposal	Logistics	Ancillary	Emergency Evacuation
50%									
90%			ADD: *Oil/ice recovery vessel (1) DELETE: **Crane barge (1)	ADD: Hopper barge (1)					

* Research and development required.
** Demonstration required.

Northern Rivers

Description of the Waterways

The northern rivers that will be considered as possible spill sites are the Upper Mississippi, the Illinois Waterway, the Missouri River, the Ohio River, the Delaware River, and the Hudson River.

By definition, the Upper Mississippi River is the 850 mile portion of the river from Cairo, Illinois to Minneapolis - St. Paul. There are 27 locks in the river and all but Lock 1 have usable dimensions of 100 ft. width and either 600 or 1,200 ft. lengths. Lock 1 has dimensions of 56 ft. by 400 ft. Figure 99 is a map of the river providing the location of the major cities and towns as well as the location of the locks and dams.

The Illinois waterway is approximately 380 miles long and connects the Upper Mississippi at Alton, Illinois with Lake Michigan at Chicago. The 375 mile section of the Missouri River from Kansas City to the Mississippi and the 980 mile section of the Ohio River from Pittsburgh to the Mississippi will also be considered.

On the East Coast, two major river areas will be considered as being separate from the coastal regions. These are the 145 mile section of the Hudson from Manhattan to Albany,and the 75 mile section of the Delaware from Philadelphia to Trenton.

History of Marine Spills

A summary of winter oil spills greater than 50,000 gallons in northern rivers is presented in Table 67. It is apparent from Table 67 that groundings and collisions cause most spills, and that No. 6 fuel oil is the product that is most often spilled.

Marine Traffic

A summary of petroleum product transportation is presented in Table 68. All of the rivers under consideration except the Missouri River are used to transport significant amounts of gasoline, distillate fuel oils, and residual fuel oils. Only the Hudson and Delaware rivers have a significant amount of traffic of self-propelled tankers. The Ohio River carries the highest volume of petroleum product traffic and the Hudson carries the next highest volume.

Traffic on the upper Mississippi is detailed in Figure 100. Table 69 presents the characteristics of barges and towboats that are used on the major inland waterways.

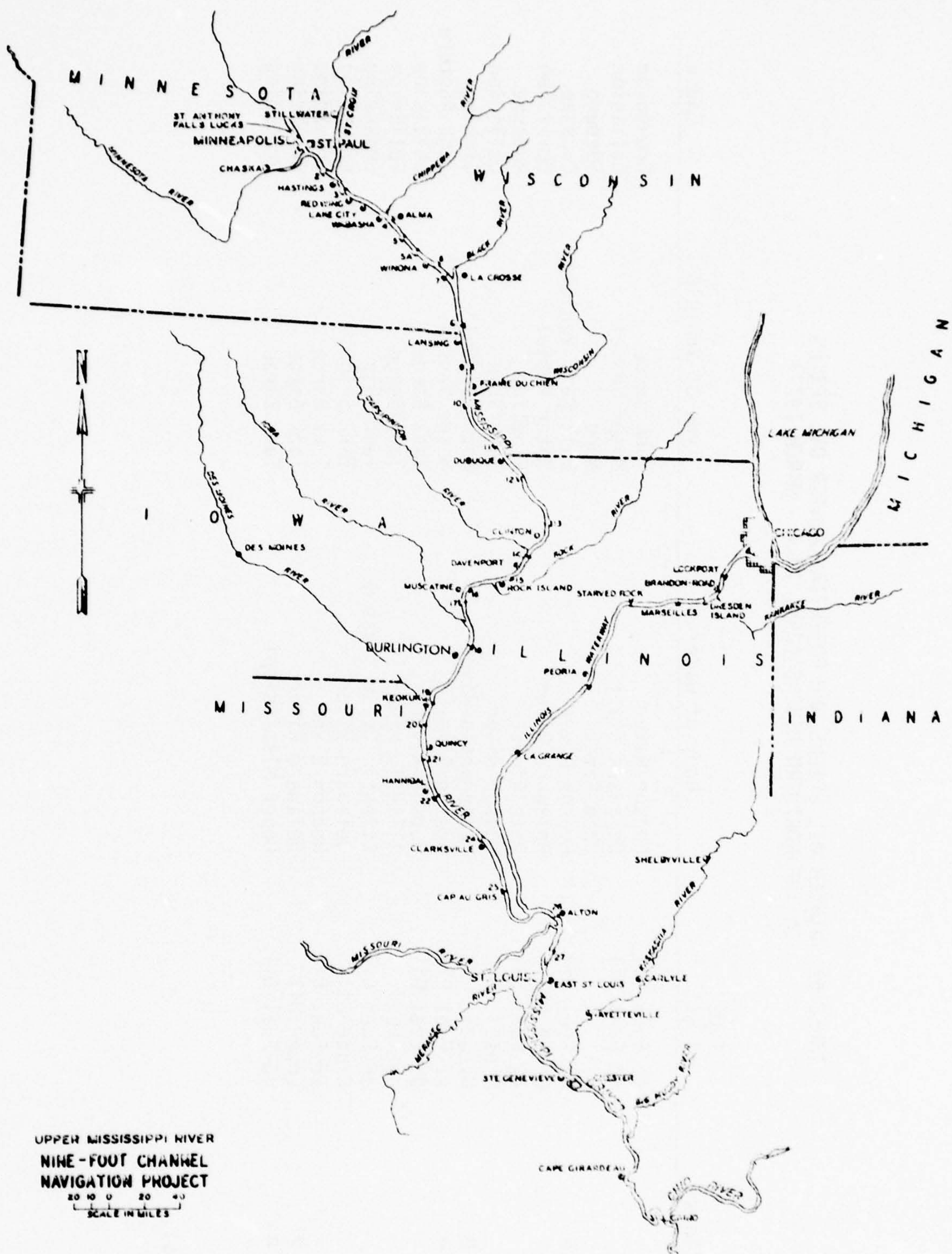


FIGURE 99. MAP OF THE UPPER MISSISSIPPI RIVER SYSTEM [24]

TABLE 67. WINTER OIL SPILLS AND POTENTIAL WINTER OIL SPILLS IN THE NORTHERN RIVERS (JAN. 1974 - MARCH 1977)

Spill Volume (gallons)	Type of Oil	Body of Water	Type of Vehicle	Cause
158,000	#6 Fuel Oil	Hudson River	Tank Barge	Grounding
258,000	#6 Fuel Oil	Delaware River	Motor Vessel	Collision
100,000	Oil	Ohio River	None	Seepage
90,000 P	#6 Fuel Oil	Hudson River	Bulk Rail Vehicle	Capsize
50,000	Crude Oil	Delaware River	Motor Vessel	Collision
60,000	#2 Fuel Oil	Ohio River	Pipeline	Rupture
90,000	Diesel	Hudson River	Tank Ship	Collision
50,000 P	Diesel	Monongahala River	Motor Vessel	Sinking
50,000 P	#2 Fuel Oil	Hudson River	Motor Vessel	Tank Rupture
90,000	#2 Fuel Oil	Hudson River	Tank Barge	Collision
225,000	Jet Fuel	Illinois River	Tank Barge	Collision
7,600,000	#6 Fuel Oil	Atlantic Ocean (Mass.)	Tank Ship	Grounding
134,000	Crude Oil	Delaware River	Tank Ship	Grounding
400,000	#6 Fuel Oil	Hudson River	Tank Barge	Grounding
21,000,000 P	Crude Oil	Delaware River	Tank Barge	Grounding
168,000 P	#6 Fuel Oil	Upper Mississippi	Tank Barge	Grounding

P = Potential

TABLE 68. MARINE TRANSPORTATION OF PETROLEUM PRODUCTS [18]

Location	Vessel Trips/Year (one way)	Product	Total Tons/Year
Upper Mississippi River (Minneapolis to mouth of the Missouri River)	1 tanker 14,618 tank barges	Crude Oil	848,337
		Gasoline	3,663,973
		Jet Fuel	307,215
		Kerosene	52,494
		Distillate Fuel Oils	2,327,271
		Residual Fuel Oils	2,625,646
Missouri River (Kansas City to the Mississippi River)	615 tank barges	Crude Oil	0
		Gasoline	48,929
		Distillate Fuel Oils	11,285
		Residual Fuel Oils	13,876
Ohio River (Pittsburgh to the Mississippi River)	10 tankers 28,179 tank barges	Crude Oil	883,282
		Gasoline	9,597,980
		Jet Fuel	862,523
		Kerosene	215,040
		Distillate Fuel Oils	4,872,882
		Residual Fuel Oils	3,177,218
Illinois Waterway (total)		Crude Oil	185,847
		Gasoline	1,566,639
		Jet Fuel	169,035
		Kerosene	13,611
		Distillate Fuel Oils	1,716,196
		Residual Fuel Oils	2,955,844
Hudson River (Mouth of Harlem River to Waterford, N.Y.)	1,359 tankers 5,747 tank barges	Crude Oil	0
		Gasoline	3,610,770
		Jet Fuel	180,874
		Kerosene	216,026
		Distillate Fuel Oils	4,085,618
		Residual Fuel Oils	3,505,226
Delaware River (Philadelphia to Trenton)	348 tankers 2,635 tank barges	Crude Oil	127,053
		Gasoline	459,301
		Jet Fuel	256,292
		Kerosene	78,302
		Distillate Fuel Oils	1,148,200
		Residual Fuel Oils	5,212,781

FIGURE 100. CARGO DIFFERENCE BETWEEN LOCKS ON UPPER MISSISSIPPI RIVER [24]

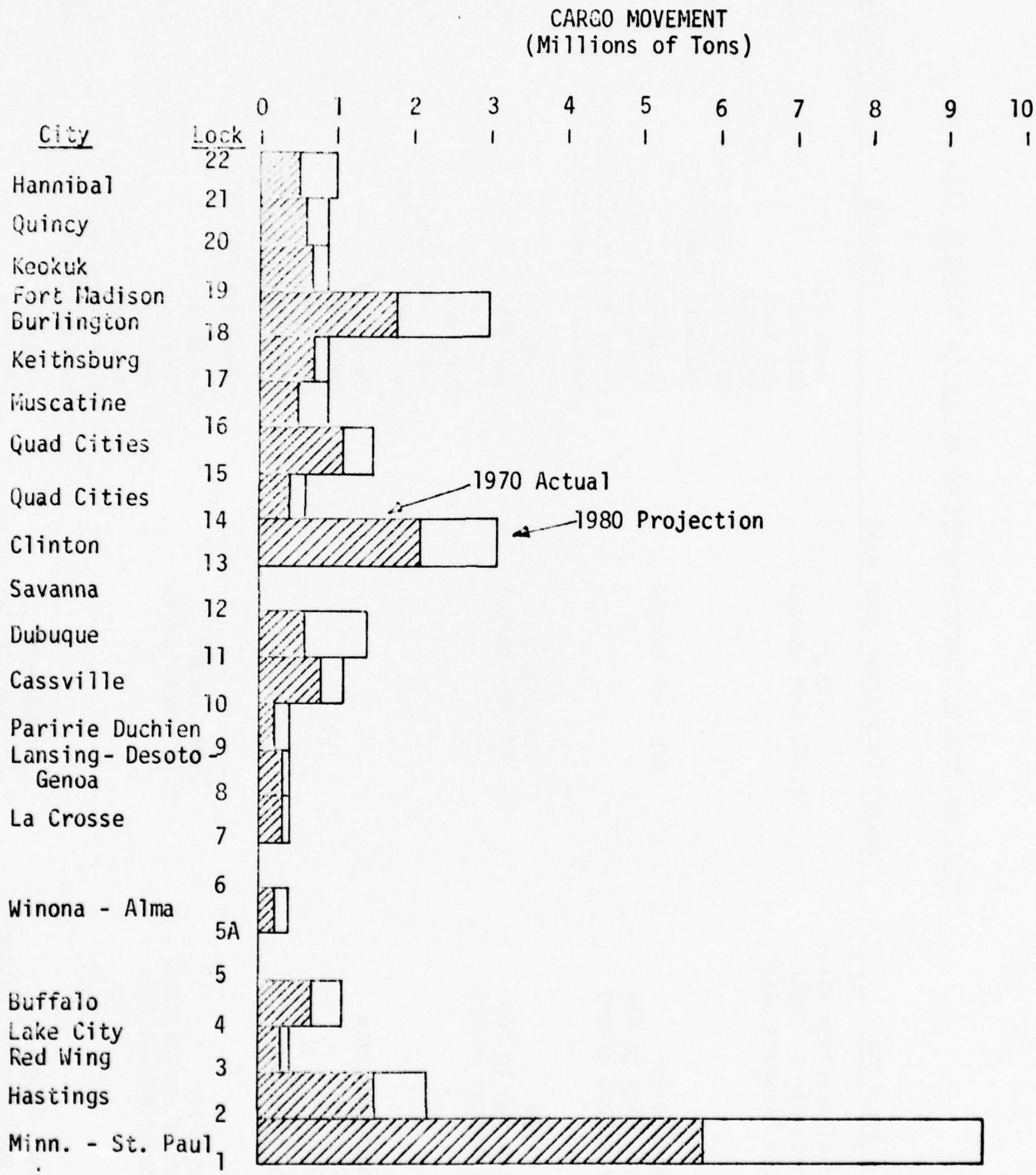


TABLE 69. CHARACTERISTICS OF RIVER BARGES AND TOWBOATS [24]

GRAIN HOPPER BARGES

Length Feet	Breadth Feet	Draft Feet	Capacity Tons
175	26	9	1000
195	35	9	1500
290	50	9	3000

COVERED DRY CARGO BARGES

Length Feet	Breadth Feet	Draft Feet	Capacity Tons
175	26	9	1000
195	35	9	1500

LIQUID CARGO (TANK) BARGES

Length Feet	Breadth Feet	Draft Feet	Capacity Tons	Capacity Gallons*
175	26	9	1000	302,000
195	35	9	1500	454,000
290	50	9	3000	907,200

*Based on an average of 7.2 barrel per ton and 42 gallons per barrel.

TOWBOATS

Length Feet	Breadth Feet	Draft Feet	Horsepower
117	30	7.6	1000 to 2000
[illegible]	[illegible]	8	2000 to 4000
[illegible]	40	8.6	4000 to 6000

Environmental Conditions

Environmental conditions for the northern rivers are defined in the following sections under the headings of:

- Ice Conditions
- Air Temperature
- Water Depths
- Water Currents
- Waves
- Water Temperatures
- Visibility
- Precipitation
- Wind

Ice Conditions

Table 70 is a summary of the ice conditions on the upper Mississippi River. Ice conditions on the Mississippi River are a problem to winter navigation north of Lock and Dam Number 22 (mile 301) near Hanibal, Missouri. From this point south to St. Louis, there is some ice on the river but it does not limit operations on the river. The ice conditions get progressively worse north from Pool 22. Pool 22 is difficult in the winter and passage through the lock takes considerable time. At Fort Madison, the river is relatively quiet and wide with blue ice. Maximum ice thickness in this pool is 15 in. These conditions exist north to Burlington.

On the Missouri River, traffic is usually interrupted from December 1 to mid-March due to ice conditions. During a mild year approximately 100 miles of the 500 miles between St. Louis and Sioux City will be covered with rafted ice. Extreme years, like 1977, will result in stable ice cover greater than 2 ft thick on the entire 500 mile reach.

The Ohio River is usually open all year and the only ice is in the form of floes from the tributaries. Extreme years, such as 1977 can cause the closing of the river due to stationary ice cover as far south as Cairo, Illinois.

The Illinois Waterway is typically open year-round with assistance from icebreaking vessels. Ice is usually in the form of fast floes, with some jamming. In extreme years, the waterway is usually closed at some point.

The Hudson is usually frozen all the way across north of Poughkeepsie to thicknesses up to 9 inches. Some shorefast ice will be present south of there, and jams will form at bends in the river like West Point. The navigation season is typically 12 months in the lower section of the river, and 12 months for ships and 8 months for barges in the upper section. During extreme years the river will freeze across as far south as Tarrytown.

Navigation on the Delaware River is usually not affected by ice conditions as far north as Trenton. Buoy tenders are used to break up jams that

THIS PAGE IS BEST QUALITY PRACTICABLE
FROM COPY FURNISHED TO DDC

TABLE 70. TYPICAL BI-MONTHLY ICE CONDITIONS IN THE SHIPPING CHANNEL OF THE UPPER MISSISSIPPI RIVER [24]

Mileage			December 1&2	December 3&4	January 1&2	January 3&4	February 1&2	February 3&4	March 1&2	March 3&4
			Ice Thickness (inches)							
848	Lock 1	850								
815	Lock 2		1.0	6.0	12.0	15.0	18.0	18.0	10.0	3.0
797	Lock 3	800	1.0	3.0	5.0	8.0	12.0	8.0	5.0	0.0
	Lake Pepin						24.0	24.0		
753	Lock 4	750	2.0	4.0	8.0	11.0	12.0	10.0	2.0	0.0
738	Lock 5		2.0	7.0	12.0	15.0	18.0	19.0	16.0	5.0
728	Lock 5A									
714	Lock 6		2.0	5.0	9.0	10.0	12.0	13.0	8.0	0.0
702	Lock 7	700	1.0	8.0	12.0	13.0	15.0	16.0	14.0	0.0
679	Lock 8		1.0	5.0	9.0	10.0	12.0	12.0	8.0	0.0
648	Lock 9	650	2.0	5.0	9.0	10.0	12.0	12.0	8.0	0.0
615	Lock 10	600	2.0	5.0	10.0	10.0	12.0	12.0	8.0	0.0
583	Lock 11		0.0	7.1	10.9	14.0	15.3	16.3	13.8	0.0
557	Lock 12	550	0.0	4.4	9.9	12.6	17.3	16.6	12.3	0.0
523	Lock 13		0.0	4.8	10.5	13.9	14.5	15.4	8.5	0.0
493	Lock 14	500	0.0	4.1	8.5	13.6	16.5	15.8	3.8	0.0
483	Lock 15		0.0	4.6	11.3	15.3	17.0	16.1	1.0	0.0
457	Lock 16	450	0.0	5.1	10.3	14.0	14.9	13.8	2.5	0.0
437	Lock 17		0.0	4.5	10.5	14.8	15.3	15.5	0.0	0.0
410	Lock 18	400	0.0	3.5	10.4	14.8	16.0	15.0	1.5	0.0
364	Lock 19	350	0.0	2.9	8.9	12.1	13.0	11.1	2.1	0.0
343	Lock 20		0.0	2.8	8.8	10.8	12.0	9.5	0.3	0.0
325	Lock 21		0.0	2.6	7.8	11.5	10.0	8.8	0.0	0.0
301	Lock 22	300	0.0	2.4	7.6	12.8	12.3	9.4	0.0	0.0
273	Lock 24									
241	Lock 25	250								
203	Lock 26	200								
105	Lock 27									

form at bends. During extreme years, freezing occurs well into Delaware Bay and navigation can be restricted. A 110 ft. icebreaking tug is used to assist priority cargos.

Air Temperature

Average monthly air temperatures for the areas under consideration are presented in Table 71.

Water Depths

The contolling depth of the Upper Mississippi River is 9 ft.; however, the majority of the time 80% of the river is about 12 ft. deep. Most towboats have a draft of 8 ft.

The controlling depths in both the Ohio River and Illinois Waterway are 9 ft. and the controlling depth in the Missouri River is 8 ft.

The Hudson River is at least 32 ft. deep to Albany and 14 ft. deep from Albany to Waterford.

The controlling depths in the Delaware River in 1976 were 36.2 ft. to the Philadelphia Naval Base decreasing to 14.7 ft. at the Trenton Marine Terminal.

Water Currents

Water currents in the rivers vary with water discharge and local cross sectional area. Currents in the upper Mississippi as given by Ashton [24] at mile 369 range from 0.40 ft/sec in January to 1.53 ft/sec in March. Currents at mile 390 range from 0.53 ft/sec in January to 2.0 ft/sec in March.

Typical winter currents on the Missouri River are 6.5 ft/sec at Omaha and 4 ft/sec at St. Louis. Currents on the Ohio River and Illinois Waterway range from 0.5 ft/sec to 1.5 ft/sec.

The Hudson River is tidal to Albany. Flood currents range from 1.9 ft/sec at Tarrytown to 0 at Albany and ebb currents vary from 2.0 ft/sec at Tarrytown to 1.2 ft/sec at Albany. The southern portion of the river is a partially mixed estuary with a net inflow near the bottom and a net outflow near the surface. Due to the net inflow at the bottom, the outflow exceeds the river discharge in the southern portions of the river.

The Delaware River is also tidally influenced to Trenton. At Hog Island in Philadelphia, maximum flood currents are approximately 3.2 ft/sec and maximum ebbs are approximately 3.7 ft/sec. At Trenton, the flood currents are weak to nonexistent and the ebbs range up to 3.4 ft/sec. Delaware Bay is a wide shallow estuary with a net inflow on the right side (when facing upstream) and a net outflow on the left.

TABLE 71 . MEAN TEMPERATURES (°F) OF CITIES NEAR RIVERS [23]

City, State	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
MISSISSIPPI RIVER												
Minn-St. Paul, Minn	12.2	16.5	28.3	45.1	57.1	66.9	71.9	70.2	60.0	50.0	32.4	18.6
Dubuque, Iowa	17.7	22.0	32.2	47.5	58.0	67.5	71.7	70.3	61.6	51.7	35.9	23.0
St. Louis, Miss	31.3	35.1	43.3	56.5	65.8	74.9	78.6	77.2	69.6	59.1	45.0	34.6
Cairo, Ill	36.3	39.7	47.8	60.3	69.3	77.7	80.7	79.2	72.0	61.7	48.3	39.1
MISSOURI RIVER												
Sioux City, Iowa	18.0	23.4	33.2	49.4	60.9	70.3	75.3	73.5	63.4	53.1	36.3	23.5
Omaha, Neb	22.6	28.0	37.1	52.3	63.0	72.2	77.2	75.6	66.3	55.9	40.0	28.0
Lincoln, Neb	22.2	27.9	36.5	51.3	62.0	72.0	77.3	75.6	65.6	54.9	39.0	27.3
Kansas City, Miss	27.8	33.1	41.2	55.0	65.0	73.9	78.8	77.4	68.8	58.6	43.6	32.3
St. Louis, Miss	31.3	35.1	43.3	56.5	65.8	74.9	78.6	77.2	69.6	59.1	45.0	34.6
OHIO RIVER												
Pittsburgh, Penn	28.1	29.3	38.1	50.2	59.8	68.6	71.9	70.2	63.8	53.2	41.3	30.5
Charleston, W. Va	34.5	36.5	44.5	55.9	64.5	72.0	75.0	73.6	67.5	51.0	45.4	36.2
Cincinnati, Ohio	32.1	34.4	42.9	55.1	64.4	73.1	76.2	75.1	68.4	57.8	44.6	34.4
Louisville, Ken	33.3	35.8	44.0	55.9	64.8	73.3	76.9	75.9	69.1	58.1	45.0	35.6
Cairo, Ill	36.3	39.7	47.8	60.3	69.3	77.7	80.7	79.2	72.0	61.7	48.3	39.1
ILLINOIS WATERWAY												
Chicago, Ill	22.9	26.1	35.7	48.8	58.4	68.1	71.9	71.1	63.7	53.8	39.2	27.1
St. Louis, Mo	31.3	35.1	43.3	56.5	65.8	74.9	78.6	77.2	69.6	59.1	45.0	34.6
HUDSON RIVER												
Albany, N.Y.	16.0	31.5	36.7	49.7	55.0	69.4	68.5	67.4	59.0	46.5	34.9	21.4
New York, N.Y.	32.2	33.4	41.1	52.1	62.3	71.6	76.6	74.9	68.4	58.7	47.4	34.5
DELAWARE RIVER												
Philadelphia, Pa	32.3	33.9	41.9	52.9	63.2	72.3	76.8	74.8	68.1	57.4	46.2	35.2

Waves

Waves are not a factor in any of the areas under consideration. Waves can be significant in the lower Hudson River and Delaware Bay, but those areas are considered as being coastal rather than rivers.

Water Temperatures

During the winter season, water temperatures are assumed to be 32°F on the fresh water rivers, decreasing to 29°F as salinity increases near the oceans.

Visibility

In the regions under consideration, the major obstructions to vision are blowing snow and fog. The average number of days per month when these factors limit visibility to less than 1/4 mile are presented in Table 72.

There are never less than 9 hours of continuous daylight in any of the areas under consideration.

Precipitation

Average monthly snowfalls are presented in Table 73.

Wind

Monthly mean and maximum wind velocities and directions are presented in Tables 74 and 75 respectively.

Selection of Spill Scenario No. 8

The selection of the Northern River Scenario is based on traffic volume, ice conditions, and winter season navigation. Areas with a relatively high volume of petroleum traffic in potentially hazardous ice conditions are the Upper Mississippi River, the Illinois Waterway, the Hudson River, and the Delaware River.

The site selected for Scenario No. 8 is the Hudson River near West Point. This area is consistently ice covered. In average years, floes jam at the bend in the river, and in extreme years the river freezes south of this area. The Hudson carries the second highest volume of petroleum products of any waterway considered, and vessels are both self-propelled and towed.

Scenario No. 8 will consist of the release of 5,000 bbls. of No. 6 residual oil at West Point in February due to a barge grounding in a moving ice field.

TABLE 72 . NUMBER OF DAYS WITH VISIBILITY LESS THAN 1/4 MILE DUE TO FOG OR BLOWING SNOW ON THE NORTHERN RIVERS [23]

City, State	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
MISSISSIPPI RIVER												
Minn-St. Paul, Minn	4	4	4	2	1	1	0	1	1	1	3	4
Dubuque, Iowa	7	6	7	3	2	1	2	2	1	2	4	7
St. Louis, Mo	4	2	3	0	0	0	0	0	1	1	2	3
Cairo, Ill	2	2	1	0	0	0	0	0	1	1	1	2
MISSOURI RIVER												
Sioux City, Iowa	5	5	4	1	1	1	1	1	1	2	3	5
Omaha, Neb	4	4	3	1	1	0	1	1	1	1	3	4
Lincoln, Neb	4	2	4	1	0	0	0	0	1	2	3	4
Kansas City, Mo	4	4	6	2	2	1	0	0	4	2	4	4
St. Louis, Mo	4	2	3	0	0	0	0	0	1	1	2	3
OHIO RIVER												
Charleston, W.Va	8	6	4	3	8	13	17	20	17	12	6	6
Pittsburgh, Pa	5	4	4	1	1	1	2	2	3	2	3	5
Cincinnati, Ohio		No Data Available										
Louisville, Ky	3	2	2	0	0	0	1	1	1	2	1	1
Cairo, Ill	2	2	1	0	0	0	0	0	1	1	1	2
ILLINOIS WATERWAY												
Chicago, Ill	5	4	5	1	2	1	1	1	0	1	2	2
St. Louis, Mo	4	2	3	0	0	0	0	0	1	1	2	3
HUDSON RIVER												
Albany, N.Y.	5	5	4	2	2	1	1	3	4	5	3	6
New York, N.Y.		No Data Available										
DELAWARE RIVER												
Philadelphia, Pa	5	5	3	1	1	1	1	1	2	4	3	4

TABLE 73. AVERAGE MONTHLY SNOWFALL (INCHES)
FOR SELECT CITIES NEAR RIVERS [23]

City, State	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
MISSISSIPPI RIVER												
Minn-St. Paul, Minn	9.1	8.5	10.6	2.5	0.2	0.0	0.0	0.0	T	0.4	5.7	8.9
Dubuque, Iowa	8.3	7.9	10.4	2.3	0.2	0.0	0.0	0 0	0.0	0.2	2.9	9.7
St. Louis, Mo	4.1	4.1	4.5	0.3	T	0.0	0.0	0.0	0.0	T	1.3	3.5
Cairo, Ill	2.7	2.2	2.5	T	0.0	0.0	0.0	0.0	0.0	0.0	0.4	1.6
MISSOURI RIVER												
Sioux City, Iowa	6.4	5.8	7.8	1.2	0.1	0.0	0.0	0.0	T	0.4	3.0	6.1
Omaha, Neb	8.4	7.4	6.7	0.9	0.1	0.0	0.0	0.0	T	0.3	2.5	5.9
Lincoln Neb	6.7	6.5	.8	0.8	0.1	0.0	0.0	0.0	0.0	0.3	2.7	5.6
Kansas City, Mo	5.7	3.9	3.8	0.7	T	0.0	0.0	0.0	0.0	T	1.1	4.4
St. Louis, Mo	4.1	4.1	4.5	0.3	T	0.0	0.0	0.0	0.0	T	1.3	3.5
OHIO RIVER												
Charleston, W.Va	8.5	7.5	4.4	0.4	T	0.0	0.0	0.0	0.0	0.2	2.9	5.2
Pittsburgh, Pa	10.6	10.4	9.5	1.5	0.2	0.0	0.0	0.0	0.0	0.2	4.1	8.8
Cincinnati, Ohio	5.1	4.3	3.4	0.5	T	0.0	0.0	0.0	0.0	0.1	1.6	3.9
Louisville, Ky	4.9	4.3	3.9	0.1	0.0	0.0	0.0	0.0	0.0	T	1.4	2.4
Cairo, Ill	2.7	2.2	2.5	T	0.0	0.0	0.0	0.0	0.0	0.0	0.4	1.6
ILLINOIS WATERWAY												
Chicago, Ill	9.7	7.7	7.8	2.0	0.1	0.0	0.0	0.0	T	0.5	1.7	8.3
St. Louis, Mo	4.1	4.1	4.5	0.3	T	0.0	0.0	0.0	0.0	T	1.3	3.5
HUDSON RIVER												
Albany, N.Y.	14.7	15.2	11.9	2.6	0.1	0.0	0.0	0.0	0.0	0.1	4.4	16.1
New York, N.Y.	7.5	8.6	5.2	0.9	T	0.0	0.0	0.0	0.0	T	1.0	5.9
DELAWARE RIVER												
Philadelphia, Pa	5.4	6.1	3.8	0.2	T	0.0	0.0	0.0	0.0	T	0.7	4.2

T indicates trace amounts.

TABLE 74. MEAN WINDS (MPH) AND PREVAILING DIRECTION FOR SELECT CITIES [23]

City, State	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
	Mean Wind Speed (mph) Direction of Wind											
MISSISSIPPI RIVER												
Minn-St. Paul, Minn	10.4 NW	10.6 NW	11.3 NW	12.3 NW	11.4 SE	10.5 SE	9.3 S	9.1 SE	9.8 S	10.4 SE	11.0 NW	10.3 NW
Dubuque, Iowa	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
St. Louis, Miss	10.3 NW	10.9 NW	11.8 WNW	11.3 WNW	9.4 S	8.6 S	7.7 S	7.4 S	7.9 S	8.5 S	9.8 S	10.2 WNW
Cairo, Ill	9.8 SW	9.8 NE	10.6 SW	10.2 SW	8.2 SW	7.4 SW	6.5 SW	6.2 NE	7.0 NE	7.3 S	9.1 S	9.3 S
MISSOURI RIVER												
Sioux City, Iowa	11.1 NW	11.3 NW	12.3 NW	13.3 NW	11.9 NNW	10.8 SSE	9.1 S	9.0 SSE	9.7 SSE	10.3 SSE	11.2 NW	10.7 NW
Omaha, Neb	11.1 NNW	11.5 NNW	12.7 NNW	13.2 NNW	11.4 SSE	10.6 SSE	9.1 SSE	9.2 SSE	9.7 SSE	10.1 SSE	11.2 SSE	10.8 SSE
Lincoln, Neb	9.7 NA	10.9 NA	11.8 NA	13.2 NA	10.5 NA	10.2 NA	10.1 NA	10.4 NA	9.6 NA	10.0 NA	10.1 NA	9.5 NA
Kansas City, Miss	11.0 NA	12.1 NA	12.2 NA	11.9 NA	9.6 NA	9.6 NA	8.1 NA	8.8 NA	8.6 NA	9.8 NA	11.2 NA	10.8 NA
St. Louis, Miss	10.3 NW	10.9 NW	11.8 WNW	11.3 WNW	9.4 S	8.6 S	7.7 S	7.4 S	7.9 S	8.5 S	9.8 S	10.2 WNW

TABLE 74. MEAN WINDS (MPH) AND PREVAILING DIRECTION FOR SELECT CITIES (CONT'D)

City, State	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
	Mean Wind Speed (mph) Direction of Wind											
OHIO RIVER												
Pittsburgh, Penn	10.7 WSW	11.0 WSW	11.2 WSW	10.7 WSW	9.4 WSW	8.2 WSW	7.5 WSW	7.2 WSW	7.7 WSW	8.5 WSW	10.1 WSW	10.5 WSW
Charleston, W. Va	7.6 WSW	8.0 WSW	8.6 WSW	7.8 SW	6.3 SW	5.6 SW	5.1 S	4.4 S	4.8 S	5.3 S	6.9 SW	7.2 SW
Cincinnati, Ohio	8.3 SW	8.4 SW	9.0 SW	8.4 SW	6.7 SW	6.4 SW	5.2 SW	5.1 SW	5.4 SW	6.1 SW	7.7 SW	7.9 SW
Louisville, Ken	9.7 S	9.8 NW	10.5 NW	10.0 SW	8.1 SE	7.4 S	6.7 S	6.4 N	6.8 SE	7.2 SE	9.0 S	9.3 S
Cairo, Ill	9.8 SW	9.8 NE	10.6 SW	10.2 SW	8.2 SW	7.4 SW	6.5 SW	6.2 NE	7.0 NE	7.3 S	9.1 S	9.3 S
ILLINOIS WATERWAY												
Chicago, Ill	11.5 SW	11.6 SW	11.7 SW	12.2 NE	10.6 NW	9.1 SW	7.9 SW	8.1 SW	8.7 WW	9.7 NW	10.9 W	10.8 W
St. Louis, Mo	10.3 NW	10.9 NW	11.8 WNW	11.3 WNW	9.4 S	8.6 S	7.7 S	7.4 S	7.9 S	8.5 S	9.8 S	10.2 WNW

TABLE 74. MEAN WINDS (MPH) AND PREVAILING DIRECTION FOR SELECT CITIES (CONT'D)

City, State	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
	Mean Wind Speed (mph) Direction of Wind											
HUDSON RIVER												
Albany, N.Y.	9.8 WNW	10.4 WNW	10.6 WNW	10.5 WNW	9.1 S	8.1 S	7.3 S	7.0 S	7.3 S	8.0 S	8.9 S	9.2 S
New York, N.Y.	10.7 NW	10.9 NW	11.0 NW	10.5 NW	8.8 SW	8.1 SW	7.7 SW	7.6 SW	8.1 SW	8.9 SW	9.9 NW	10.4 NW
DELAWARE RIVER												
Philadelphia, Pa	10.3 WNW	11.2 NW	11.5 N	11.1 SW	9.7 WSW	8.8 WSW	8.1 WSW	7.9 SW	8.3 SW	8.9 WSW	9.7 WSW	10.1 WNW

TABLE 75. FASTEST WIND SPEEDS (MPH) AND THE PREVAILING DIRECTION FOR SELECT CITIES [23]

City, State	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
	Fastest Wind Speed (mph) Direction of Wind											
MISSISSIPPI RIVER												
Minn.-St. Paul, Minn	40 SE	42 NW	47 E	52 WSW	61 NW	63 NW	92 W	63 N	47 N	73 S	60 SW	52 W
Dubuque, Iowa	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
St. Louis, Miss	39 W	46 NW	45 NE	34 W	42 SE	60 SE	40 NW	48 NW	39 SW	48 SW	41 S	44 W
Cairo, Ill	50 SW	45 SW	60 NW	59 SW	49 SW	60 SW	45 SW	44 NW	36 NW	40 SW	53 SW	63 SW
MISSOURI RIVER												
Sioux City, Iowa	56 NW	54 NW	61 N	68 W	80 W	91 W	66 NW	56 NW	66 S	70 W	59 NW	53 NW
Omaha, Neb	57 NW	57 NW	73 NW	65 NW	73 NW	72 N	109 N	66 N	47 E	62 NW	56 NW	52 NW
Lincoln, Neb	42 N	48 NW	54 N	49 SW	51 W	38 SW	51 NW	43 N	34 S	38 S	48 NW	40 NW
Kansas City, Miss	37 SW	38 NW	42 E	40 SE	42 SW	32 S	70 NW	30 W	33 NW	35 S	34 NE	50 N
St. Louis, Miss	39 W	46 NW	45 NE	45 W	42 SE	60 SE	40 NW	48 NW	39 SW	48 SW	41 S	44 W

TABLE 75. FASTEST WIND SPEEDS (MPH) AND THE PREVAILING DIRECTION FOR SELECT CITIES (CONT'D)

City, State	Fastest Wind Speed (mph) Direction of Wind											
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
OHIO RIVER												
Pittsburgh, Penn	48	58	48	46	42	40	51	46	32	35	45	48
	W	W	WSW	W	WSW	W	WSW	WNW	NNE	W	WNW	WSW
Charleston, W. Va	45	40	46	45	55	50	46	50	35	45	40	55
	NW	NW	NW	NW	NW	NW	NW	NW	NW	NW	NW	NW
Cincinnati, Ohio	49	49	49	47	36	40	43	38	38	35	47	41
	SW	SW	SW	SW	W	W	SW	W	SW	SW	SW	SW
Louisville, Ken	50	61	56	57	57	58	60	52	57	38	60	61
	S	NW	W	W	W	W	NW	NW	NW	SE	SE	SW
Cairo, Ill	50	56	60	59	49	60	45	44	36	40	53	63
	SW	SW	NW	SW	SW	SW	NW	NW	NW	SW	SW	SE
ILLINOIS WATERWAY												
Chicago, Ill	47	45	54	54	52	41	53	46	58	48	51	46
	W	SW	N	SW	NW	SW	NW	NW	SW	NE	SW	SW
St. Louis, Mo	39	46	45	45	42	60	40	48	39	48	41	44
	W	NW	NE	W	SE	SE	NW	NW	SW	SW	S	W

TABLE 75. FASTEST WIND SPEEDS (MPH) AND THE PREVAILING DIRECTION FOR SELECT CITIES (CONT'D)

City, State	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
	Fastest Wind Speed (mph) Direction of Wind											
HUDSON RIVER												
Albany, N.Y.	57 W	71 NW	55 W	49 W	50 W	57 NW	43 NW	38 S	48 S	45 NW	70 E	54 W
New York, N.Y.	47 NW	47 NE	60 NW	45 NE	38 NE	49 SW	43 NW	36 NE	44 NE	40 NE	70 NE	43 NW
DELAWARE RIVER												
Philadelphia, Pa	61 NE	59 NW	56 NW	59 SW	56 SW	73 NW	47 W	67 E	49 NE	66 SW	60 SW	47 NW

Spill Mode

The northern rivers oil spill scenario selected consists of the instantaneous release of 5,000 barrels of No. 6 residual fuel oil in the Hudson River at a turn near West Point, resulting from the grounding of a barge in a moving ice field in the month of February.

Spill Environmental Conditions

Shorefast ice approximately 9 inches in thickness will cover about 25% of the river surface along the shore of the river and in protected areas. Ice floes, ranging in size from an average dimension of 20 ft to a maximum of 300 ft across, will be moving under the influence of tides and winds and will cover approximately 55% of the river. There will be an ice jam at the bend in the river at West Point. Average air temperatures will be 31°F in February, increasing to 37°F in March. Minimum air temperatures are typically 17°F in February, and 24°F in March. The controlling depth of the river is 32 ft. Tidal currents are semi-diurnal, with a 0.8 knot flood tide and a 1.2 knot ebb. Surface waters in the area exhibit a net flow seaward of 0.2 knots in the month of February.

Visibility can be expected to be reduced to less than 1/4 mile due to fog or blowing snow about one day per week in the months of February and March. There will be at least nine hours of daily daylight. Typically, 3 inches of new snow can be expected each week in February, with 2 inches of new snow expected per week in March. Winds will typically be 10 mph from the west-northwest in February, and 11 mph from the same direction in March. Maximum observed winds have been recorded as 47 mph northeast in February, and 60 mph northwest in March. Waves will not be a factor in this scenario. The storm history for the area indicates that one storm can be expected in the month of February, with one additional storm expected in the month of March.

Spill Behavior

The combined flood and ebb tidal currents result in an average tidally induced downstream flow of 0.2 knots, or 5 statute miles per day. The ice will move at a speed less than that of the surface waters, however, due to the presence of ice jams and bank friction. Oil which was spilled 6 miles south of West Point from the barge ETHEL H in 1977 moved downstream at an average rate of 3.5 miles per day. The first oil is projected to reach the Atlantic Ocean, which is 50 miles downstream, about 14 days after the spill occurs.

It has been estimated that approximately 10% of the No. 6 fuel oil will be lost due to weathering during the two week period between the spill incident and the time at which the oil will reach the Atlantic Ocean. Although the average air temperature will only be 31°F, there will be some days when the temperature is above 40°F, which will accelerate the weathering process. In addition, most of the oil will be exposed to the atmosphere on the surface of the water. It is estimated that only 5% of this spilled oil will penetrate the solid ice since the low salinity ice is relatively non-porous.

Based on the experience gained in observing the behavior of the oil spilled in the 1977 ETHEL H spill, about 40% of the oil is expected to be found adhering to ice floes. Oil will be present under, on top of, and around the edge of these floes. Any oil on top of the ice will reduce the solar albedo, causing melt holes to form in the ice floes. Due to the relatively strong tidal currents, very little oil is expected to remain beneath the ice floes. It is also expected that no significant amount of oil will be located under the shorefast ice since the edge of the shorefast ice serves as an effective containment mechanism, protecting the shore from contamination by the oil. The remaining 45% of the spilled oil is expected to float on open water between the ice floes. Oil thicknesses will range from a thin sheen in areas of primarily open water, to as much as one inch where the ice floes are relatively concentrated. The condition of the spilled oil shortly after the spill occurs is shown conceptually in the sketch of Figure 101.

Spill Response

The oil spill will be detected visually by the crew of the tug handling the barge, and will be reported to the Coast Guard by way of the tug's radio.

Initial surveillance will be performed by the crew of the tug. Subsequent surveillance will require the use of helicopters and other marine vessels. Since little oil will be located beneath the shorefast ice, visual surveillance of the oil slick should be adequate. It is estimated that one helicopter overflight per day would be required to monitor the downstream movement of the oil to achieve a 25% response level, and two overflights per day would be required to achieve higher response levels. Marking buoys placed on the larger ice floes would be valuable for marking the limits of the spill since 3 inches of snow which would limit visual detection of the spilled oil can be expected within one week of the spill incident.

Conventional oil containment booms would be of little value in the moving ice field. A combination ice boom and oil containment boom could be installed across the river downstream of the spill in a manner so as to separate the oil from the ice field with the ice boom, and subsequently gather the oil with the containment boom. However, it has been estimated that it would take approximately one week to install the combined ice/oil boom system, by which time the oil will have contaminated areas as far as 25 miles downstream, and the areal coverage of the spill will have increased to the point where this approach would be unmanageable. Containment booms could however be deployed at power generating stations along the river to protect their cooling systems from contamination by the oil. Little other shoreline protection will be called for since there will be a substantial amount of natural shoreline protection due to the presence of the shorefast ice.

In situ burning of the spilled oil will not be a feasible recovery technique for use in this scenario since in a short period of time the thickness of the oil will be relatively thin and the oil will subsequently be at a temperature below its pour point. Direct suction will also be of little value since most of the oil will be adhering to ice floes or spread relatively thinly

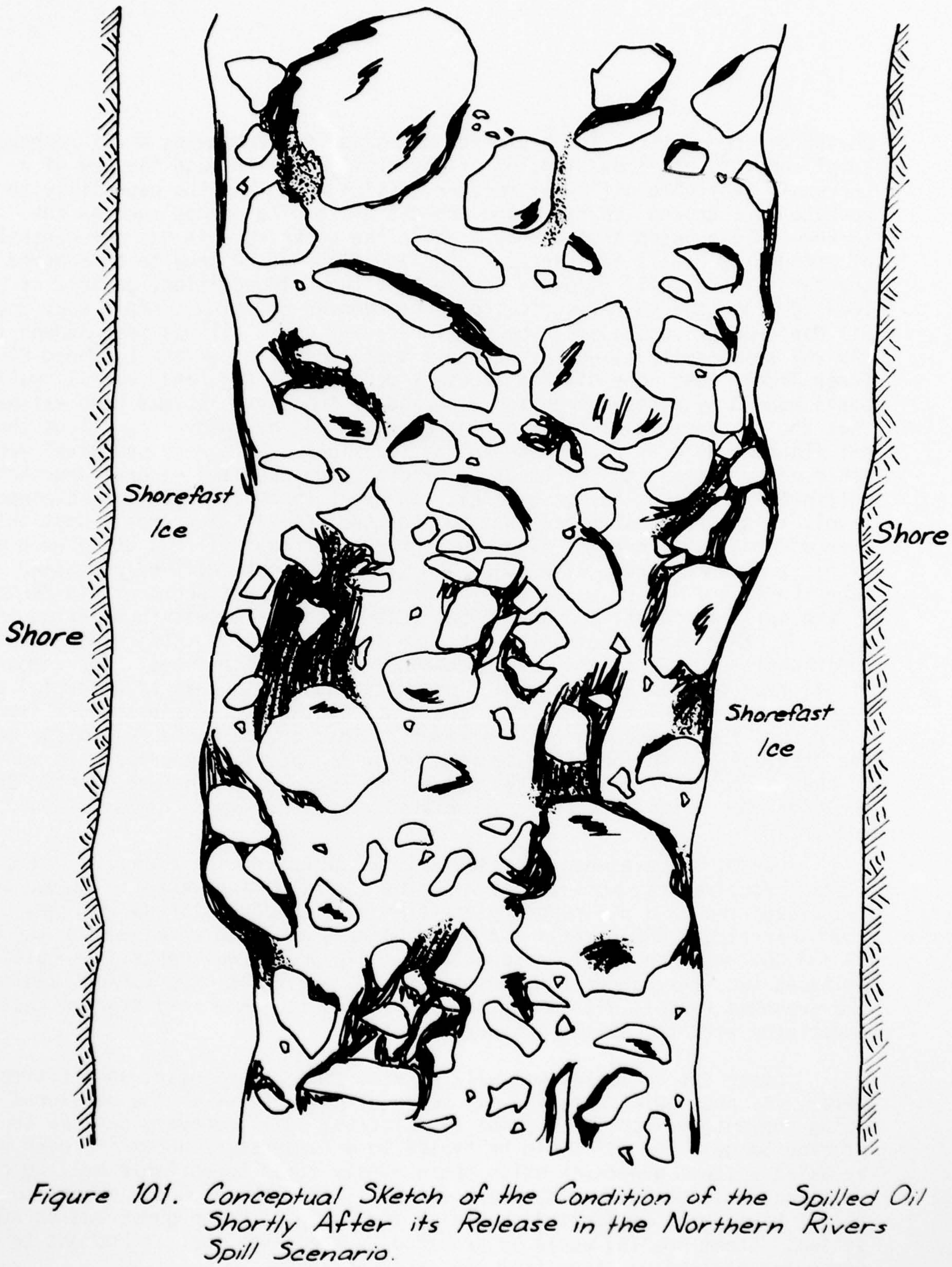


Figure 101. Conceptual Sketch of the Condition of the Spilled Oil Shortly After its Release in the Northern Rivers Spill Scenario.

on top of open water. The preferred technique for achieving a 25% response level consists of recovering 25% of the spilled oil through the use of a currently available oil spill recovery device which has the capability to operate in a broken ice field and process broken ice pieces such as the Lockheed Clean Sweep Arctic Boat. While the Lockheed unit has the capability of processing small ice pieces, large ice floes would have to be removed from the path of the spill recovery device by a tug. In addition, pockets of oil located along the shorefast ice could be removed by using a small boat mounted Oil Mop type of continuous rope spill recovery unit. It has been judged that the 25% response level would require a team consisting of one Lockheed Clean Sweep Arctic Boat, one Oil Mop recovery device, one tug, and several small boats manned by nineteen men for a period of ten days. It has been estimated that the response level could be increased to 45% by recovering all of the oil floating on open water between the ice floes. This response level can be achieved by increasing the level of effort using the same general approach outlined for the 25% response level. In order to achieve the 45% response level, it has been estimated that two Lockheed Clean Sweep Arctic Boat units each manned with a crew of nine men, three small boat Oil Mop units each manned with a twelve man crew, five tugs, and six small boats will be necessary. In both the 25 and 45% response level cases, recovery must begin within 24 hours of the spill incident, and operations must be completed within a period of ten days. Further extension of the response level from 45 to 80% requires the additional recovery of the oil which adheres to the ice floes. The removal of oil from the contaminated ice floes will require the use of a special oil/ice recovery vessel which can recover the contaminated ice, clean the oil from it, and return the cleaned ice to the river. This device would be similar to the one previously described for use in some of the arctic scenarios. In addition to the special oil/ice recovery vessel, one Lockheed Clean Sweep Arctic Boat, three Oil Mop units, and their associated crews and support vessels would be required.

Due to the presence of relatively large moving ice floes, all temporary storage requirements must be met with the use of marine vessels. Based on the assumption of a 50% recovery efficiency, temporary storage volumes of 2,500 barrels, 4,500 barrels and 8,000 barrels would be required for the 25, 45 and 80% response levels respectively. The preferred scenario is based on bringing two tank barges to the spill scene; one to be used for offloading the grounded vessel, with the other serving as the temporary storage vessel associated with the spill recovery operations.

Since the recovered oil will be at a temperature near, and at times below, its pour point, heating may be required to transfer the recovered oil using conventional portable pumps from the oil spill recovery devices to the storage barge. The oil could be heated to a temperature above its pour point by using a steam generator which could supply steam to portable heating coils or directly to the oil. The transfer of oil from the grounded vessel to a relief barge will be accomplished with the vessel's cargo pumps and an ADAPTS system. Steam heating would be provided by the barge that is brought to the scene for offloading cargo from the stricken vessel.

AD-A058 782 ARCTEC INC COLUMBIA MD F/G 13/2
SYSTEMS FOR ARCTIC SPILL RESPONSE. VOLUME I.(U)
MAR 78 L A SCHULTZ, P C DESLAURIERS DOT-CG-71343-A
UNCLASSIFIED 405C-3-VOL-1 USCG-D-44-78-VOL-1 NL

4 OF 4
AD
A058 782

END
DATE
FILMED
-11-78
DDC

The relative proximity of oil processing facilities resulted in the selection of shoreside processing for final disposal of the recovered oil.

The logistics effort will be based out of a staging area established onshore at West Point, or at Buchanan, located 12 miles downstream of the spill site. Recovery equipment and personnel will be transported to the scene by marine vessels from the New York City area. Local helicopters and fixed wing aircraft will be used for the transportation of personnel and equipment, and for surveillance of the spilled oil.

Weather forecasts will be required on an hourly basis for the guidance of the spill response effort. River current predictions should also be made on an hourly basis based on the Corps of Engineers Tidal Current Tables and river discharge rates. With the use of this data, it should be possible to predict the location of the downstream edge of the oil slick with a reasonable degree of accuracy. Medical facilities will be available at any of the numerous hospitals in communities located along the lower Hudson River. A special emergency helicopter will not be required since emergency cases could quickly be taken ashore and transported to nearby medical facilities with the use of conventional emergency vehicles.

The preferred spill response techniques for the northern rivers spill scenario are summarized in Table 76. The equipment required to achieve the 25, 45 and 80% response levels for this scenario is summarized in Tables 77 and 78.

TABLE 76. SUMMARY OF PREFERRED SPILL RESPONSE TECHNIQUES FOR THE NORTHERN RIVERS SPILL SCENARIO

Function	25% Response Level	45% Response Level	80% Response Level
Detection	Visual by crew of tug	Same	Same
Surveillance	Initially by crew of tug; then by helicopters and response vessels	Same	Same
Containment	Shoreline protection	Same	Same
Recovery	Open water devices and ice management	Same	Same plus special oil/ice recovery vessel
Storage	Tank barge	Same	Same
Transfer	Portable pumps with steam generator for heating oil	Same	Same
Disposal	Shore side oily waste processing plant	Same	Same
Logistics	Staging area at West Point or Buchanan, equipment and personnel from New York City	Same	Same
Ancillary	Weather and current forecasts	Same	Same
Emergency Evacuation	Marine vessel to shore side emergency vehicles	Same	Same

TABLE 77. EQUIPMENT REQUIRED TO ACHIEVE THE 25% RESPONSE LEVEL FOR SCENARIO NO. 8

Subsystem	Item	No. Req'd.	Specifications	Weight/Volume
Surveillance	Helicopter	1		
Containment	**Conventional high seas oil boom suitable for use in light ice fields	5,000 ft.	14"	6,250 lbs.
Recovery	Conventional oil recovery device capable of processing small ice pieces	1	Arctic Boat or ZRV	14,000 lbs. ea.
	Oil Mop	1	Mark II-4H	
Storage	Tank barges	2	10,000 bbl with pumps	
	Bladder tanks	2	1,000 gal. ea.	100 lbs. ea.
Transfer	Portable pumps	2	200 gpm self-priming with hose	
	ADAPTS	1	1,000 gpm @ 32 ft. disch.	
	Steam generators	2	4,000,000 BTU/hr each	5,700 lbs. ea.
Disposal	None			
Logistics	Tugs	3		
	C-130	1		
	Floating platform	2	16' workboats	
Ancillary	Weather forecasts	Daily		
	Current prediction	Daily		
	Communications equipment			
Emergency Evacuation	Helicopter (listed above)			

**Demonstration required.

TABLE 78. VARIATIONS IN EQUIPMENT REQUIRED TO ACHIEVE THE 45% and 80% RESPONSE LEVELS FOR SCENARIO NO. 8

Response Level	Surveillance	Containment	Recovery	Storage	Transfer	Disposal	Logistics	Ancillary	Emergency Evacuation
45%		ADD: **Conventional high seas oil boom suitable for use in ice fields (10,000 ft.)	ADD: Arctic Boat or ZRV (2) Oil Mop Mark II-4H (3)	ADD: Bladder tanks (4)			ADD: Tug (1) Floating platforms (2)		
80%		ADD: **Conventional high seas oil boom suitable for use in ice fields (10,000 ft.)	ADD: *Oil/ice recovery vessel (1) Arctic Boats or ZRV (2) Oil Mop Mark II-4H (3)	ADD: Bladder tanks (4)			ADD: Tugs (2) Floating platforms (2)		

* Research and development required.
** Demonstration required.

Northern Coastal Regions

Description of Region

The coastal regions of the continental United States that are significantly affected by ice are limited to the Northeast Coast shown in Figure 102. Although the Northwest and Middle Atlantic coastal regions do experience ice during severe winters, it rarely affects navigation in those areas.

Areas of concentrated marine traffic that will be considered as possible spill sites are the Port of New York, the Cape Cod Canal area, Boston Harbor, and Portland, Maine. These are the major traffic areas on the Northeast Coast where navigation can be affected by ice conditions.

History of Marine Oil Spills

A summary of winter oil spills and potential winter oil spills from January 1974 to March 1977 is presented in Table 79. Most spills are the result of groundings or collisions and New York Harbor has had more incidents than any other northeastern coastal area.

Marine Traffic

The major commercial traffic on the Northeast Coast is to and from the larger ports. This traffic consists of ocean-going vessels and coastal barges and ships. A summary of the petroleum product traffic in the areas of interest is presented in Table 80.

Environmental Conditions

Environmental conditions for the Northeastern coastal region are defined in the following sections under the headings of:

Ice Conditions
Air Temperatures
Snowfall
Wind
Tidal Ranges
Tidal Currents
Visibility

Ice Conditions

Ice generally does not grow more than one foot thick; however, movement with the tidal currents causes rafting to three or four feet. Ice seldom poses a problem to navigation in the major harbors. New York, Boston, and Portland harbors remain relatively ice free due to the tides, their proximity to the open ocean, and high traffic levels.

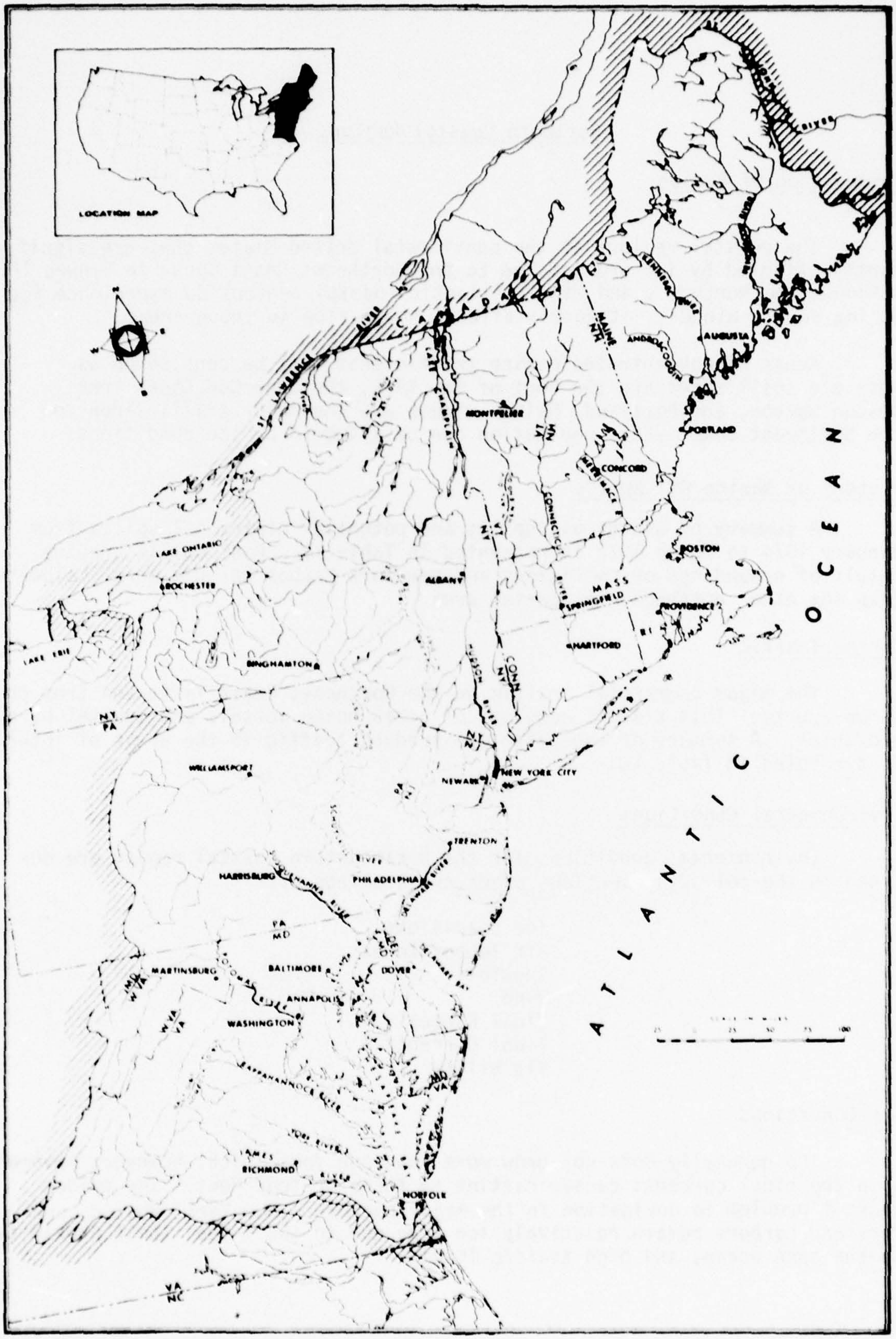


FIGURE 102. MAP OF THE NORTHEASTERN COAST OF THE UNITED STATES

TABLE 79. WINTER OIL SPILLS AND POTENTIAL WINTER OIL SPILLS FOR SELECT GEOGRAPHIC AREAS (JAN. 1974 - MARCH 1977) [25]

Spill Volume (gallons)	Type of Oil	Body of Water	Type of Vehicle	Cause
50,000 P	Crude Oil	Delaware Bay	Tank Ship	Collision
330,000 P	Mixed Products	Atlantic Ocean (N.Y.)	Tank Ship	Personnel Error
100,000 P	Diesel	New York Harbor	Tank Barge	Grounding
5,880,000 P	#4 Fuel Oil	New York Harbor	Tank Ship	Grounding
9,200,000 P	Mixed Products	Delaware Bay	Tank Ship	Collision
5,500,000 P	Diesel	Atlantic Ocean (N.H.)	Tank Ship	Storm Damage
100,000 P	#6 Fuel Oil	New York Harbor	Tank Ship	Collision
100,000 P	Mixed Products	New York Harbor	Tank Ship	Collision
693,000 P	Diesel	New York Harbor	Tank Barge	Grounding
100,000	#2 Fuel Oil	Buzzards Bay	Tank Barge	Grounding

Note: "P" indicates potential spill volume

TABLE 80. MARINE TRANSPORT OF PETROLEUM PRODUCTS FOR THE NORTHEAST COAST [18]

Location	Vessel Trips/Year (one way)		Product	Total Tons/Year
Portland, Maine	Tankers	2,424	Crude Oil	19,545,592
	Tank Barges	477	Gasoline	2,327,364
			Jet Fuel	64,381
			Kerosene	156,615
			Distillate Fuel Oils	1,823,871
			Residual Fuel Oils	1,316,816
Boston, Mass	Tankers	3,382	Crude Oil	54,999
	Tank Barges	1,288	Gasoline	6,196,597
			Jet Fuel	666,697
			Kerosene	697,755
			Distillate Fuel Oils	7,599,439
			Residual Fuel Oils	7,750,260
Cape Cod Canal, Mass	Tankers	1,867	Crude Oil	145,364
	Tank Barges	1,971	Gasoline	4,014,695
			Jet Fuel	168,612
			Kerosene	97,598
			Distillate Fuel Oils	2,530,706
			Residual Fuel Oils	3,060,408
New York Harbor N.Y., Including Port Newark	Tankers	14,303	Crude Oil	24,905,193
	Tank Barges	26,645	Gasoline	23,685,168
			Jet Fuel	1,908,020
			Kerosene	2,212,935
			Distillate Fuel Oils	29,173,002
			Residual Fuel Oils	51,086,834

Ice is usually not a problem in the Cape Cod Canal, but it is a problem at the Buzzards Bay entrance to the canal. The bay will freeze up to one-foot thick. As the ice is broken up by the tide, rafting to three or four feet occurs. It is packed into the entrance of the canal by tidal currents. Icebreaking assistance by 110-foot tugs is required out to Cleveland Ledge.

Fishing fleets in the small harbors along the coast frequently request icebreaking assistance. This has been provided by 65-foot tugs when they are available.

Air Temperatures

Average monthly air temperatures for the areas under consideration are given in Table 81. Portland experiences 5 months of below freezing temperatures, while Boston and New York experience below freezing temperatures for 4 months and 3 months respectively.

Snowfall

Table 82 presents the average monthly snowfalls for Portland, Boston, and New York. All three areas have significant amounts of snowfall from December through March.

Wind

Mean and maximum wind velocities and the associated prevailing directions are given in Tables 83 and 84 respectively.

Tidal Ranges

The East Coast tides are semi-diurnal; that is, there are two highs and two lows each day. The range of tide varies from twenty feet at Eastport, Maine, to one foot at Baltimore, Maryland. Ranges at other locations are:

Bucksport, Maine	12 ft.
Bath, Maine	7 ft.
Portland, Maine	10 ft.
Boston, Mass.	10 ft.
New Bedford, Mass	4 ft.
New York City	5 ft.

Tidal Currents

Maximum tidal currents are presented in Table 85. The three harbors exhibit a net flow seaward, and the net flow through the Cape Cod Canal and Buzzards Bay is westerly.

Visibility

The average monthly number of days with limited visibility due to fog and blowing snow is given in Table 86.

TABLE 81. AVERAGE TEMPERATURES (°F) FOR SELECT NORTHEAST COASTAL PORTS [23]

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Portland	11.7	12.5	22.8	32.5	41.7	51.1	56.9	55.2	47.4	38.0	29.7	16.4
Boston	22.5	23.3	31.5	40.8	50.1	59.3	65.1	63.3	56.7	47.5	38.7	26.6
New York	25.9	26.5	33.7	43.5	53.1	62.6	68.0	66.4	59.9	50.6	40.8	29.5

TABLE 82. AVERAGE MONTHLY SNOWFALL FOR SELECT CITIES (Inches) [23]

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Portland	17.7	19.9	13.7	3.1	0.3	0.0	0.0	0.0	T	0.3	3.4	15.8
Boston	12.0	11.9	8.0	0.7	T	0.0	0.0	0.0	0.0	T	1.2	8.2
New York	7.5	8.6	5.2	0.9	T	0.0	0.0	0.0	0.0	T	1.0	5.9

T = Trace Amount

TABLE 83. MEAN WIND VELOCITY IN MPH AND PREVAILING DIRECTION FOR SELECT NORTHEAST COASTAL PORTS [23]

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Portland	9.2 N	9.6 N	10.1 W	10.0 S	9.2 S	8.2 S	7.7 S	7.5 S	7.8 S	8.5 N	8.8 W	9.1 N
Boston	14.2 NW	14.2 WNW	14.0 NW	13.4 WNW	12.2 SW	11.4 SW	10.8 SW	10.8 SW	11.3 SW	12.2 SW	13.1 SW	13.8 WNW
New York	10.7 NW	10.9 NW	11.0 NW	10.5 NW	8.8 SW	8.1 SW	7.7 SW	7.6 SW	8.1 SW	8.9 SW	9.9 NW	10.4 NW

TABLE 84. FASTEST WINDS (MPH) AND PREVAILING DIRECTION FOR SELECT NORTHEAST COASTAL PORTS [23]

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Portland	50 SE	58 N	76 NE	57 S	49 NW	45 SW	44 W	69 E	62 SE	45 N	76 NE	62 SE
Boston	61 NW	57 S	55 SW	52 NW	50 NE	40 SW	45 N	45 SW	57 S	45 NW	54 NE	49 NW
New York	47 NW	47 NE	60 NW	45 NE	38 NE	49 SW	43 NW	36 NE	44 NE	40 NE	70 NE	43 NW

TABLE 85. TYPICAL MAXIMUM TIDAL CURRENTS (KNOTS) [26]

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Portland	1.5	1.6	1.7	1.7	1.8	1.8	1.7	1.6	1.6	1.6	1.8	1.7
Boston	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.7	1.8	1.8	1.6
Buzzard's Bay	1.2	1.3	1.4	1.3	1.4	1.4	1.4	1.3	1.3	1.4	1.4	1.3
New York	2.2	2.3	2.3	2.4	2.4	2.7	2.5	2.4	2.4	2.4	2.7	2.7

TABLE 86. VISIBILITY DUE TO FOG AND BLOWING SNOW - NUMBER OF DAYS WITH 1/4 MILE OR LESS VISIBILITY [23]

	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec
Portland	6	6	7	4	6	6	7	6	6	5	4	2
Boston	5	5	4	2	3	2	2	2	2	2	2	3
New York	4	4	4	2	3	2	2	2	2	2	2	3

Selection of Spill Scenario No. 9

Alternative spill scenarios for coastal regions are limited to high traffic areas on the East Coast and north of New York City. As stated previously, ice conditions seldom affect navigation south of New York or on the Northwest Coast. Therefore, the areas under consideration are Portland, Maine; Boston and Portsmouth, Massachusetts; the Cape Cod Canal area, and New York Harbor (including New Jersey).

The selected scenario consists of the total loss of a barge at Cleveland Ledge in Buzzards Bay, resulting in a 5,000 bbl (210,000 gallons) spill of No. 2 fuel oil in February. Buzzards Bay is selected as the spill site since ice conditions are potentially more hazardous to navigation than in the other areas. Floes of rafted ice up to 4 ft. thick move about the bay under the influence of strong tidal currents and winds. Also, this area is a major artery in the coastal traffic pattern. Although traffic levels are not as high as they are in the major harbors, the channel is relatively narrow and the ice is contained in the bay. Most of the major harbors are less sheltered from the ocean and have a net river flow seaward, so ice conditions are seldom as severe as they can be in Buzzards Bay.

Spill Mode

The oil spill scenario selected for the northern coastal area consists of the total loss of a coastal barge due to a grounding at Cleveland Ledge in Buzzards Bay, Massachusetts, resulting in the release of 5,000 barrels of No. 2 fuel oil.

Spill Environmental Conditions

The Buzzards Bay spill scenario is selected to occur in February when the bay will be approximately 50% covered with shorefast ice 1 ft in thickness. The active ice field bounded by the shorefast ice will be rafted to a thickness of 3 to 4 ft, and will consist approximately 25% of hummocks and pressure ridges, and 75% of floes to as great as 150 ft in diameter. The average air temperature in February is 23°F, increasing to 31°F in March. Minimal air temperatures are typically 9°F in February, and 18°F in March. The barge is grounded in 17 ft of water at Cleveland Ledge, and the average water depth of the surrounding area is about 36 ft. Tidal currents up to 0.9 knots will be present in the vicinity of the spill site.

Visibility can be epxected to be reduced to less than 1/4 mile one day per week in the months of February and March due to heavy fog or blowing snow. Approximately 12 inches of snowfall can be expected in February, with 8 inches expected in March. Typical wind speeds in February and March are 14 mph. Winds as high as 61 mph have been experienced in February, and 57 mph in March. There will be no significant wave action due to the calming effect of the ice cover. One storm can typically be expected during the 2 month period covering February and March.

Spill Behavior

The projected behavior of the spilled oil is based upon observations made during the 1977 Buzzards Bay oil spill in ice infested waters, which was also caused by a grounding at Cleveland Ledge. In the projected scenario, however, the entire spill will be located at the Cleveland Ledge site, whereas in the 1977 spill, oil was distributed over a larger area by moving the stricken barge.

Tidal currents will transport the oil leaking from the barge beneath the surrounding shorefast ice cover. As oil passes to cracks in the ice cover, buoyant forces will cause it to surface. Where the ice is rafted, oil pools as large as 2,000 gallons in volume could form, but volumes of 200 gallons are judged to be more typical. Smaller pools of oil will be trapped between broken ice pieces in hummocks and pressure ridges. Some oil will be blown from concentrated pools across the surface of the ice. Figure 103 is a conceptual sketch of the distribution of the oil in the Buzzards Bay scenario showing oil contained with a pressure ridge, oil contained between ice floes in a broken ice field, a concentrated pool of oil in an area of rafted ice, wind blown oil on the surface of the ice originating from the concentrated pool in the rafted ice, and a fine oil sheen spreading on an open water lead in the ice.

Data collected during the 1977 Buzzards Bay oil spill revealed that after a period of twelve days 30% of the oil spilled was trapped in large pools, 16% was trapped in small pools, 30% was absorbed by ice, 15% was lost to evaporation and dissolution, and 8% had been blown by the wind on the surface of the ice. A total areal coverage of the spill is projected to be about 0.1 square miles in 3 to 5 days, with the oil pooled in varying concentrations rather than being evenly distributed. The 1977 spill also revealed after a snowfall that snow absorbed the oil such that the resulting oiled snow slush was 30% oil by volume.

Spill Response

The spill will be detected by the crew of the tug immediately after the barge grounds on Cleveland Ledge. The accident will be reported to the Coast Guard by way of the tug's radio.

Initial onscene surveillance will be carried out by the crew of the tug. Subsequent surveillance will be maintained by light aircraft and helicopters. All pools of concentrated oil should be marked as soon as possible to facilitate relocation by recovery teams in the event of coverage of the area by snow.

Because of the relatively severe ice conditions, no containment activities will be possible related to this scenario. However, as previously indicated, a significant amount of natural containment will be provided by the discontinuous ice features. Although the total area of coverage of the

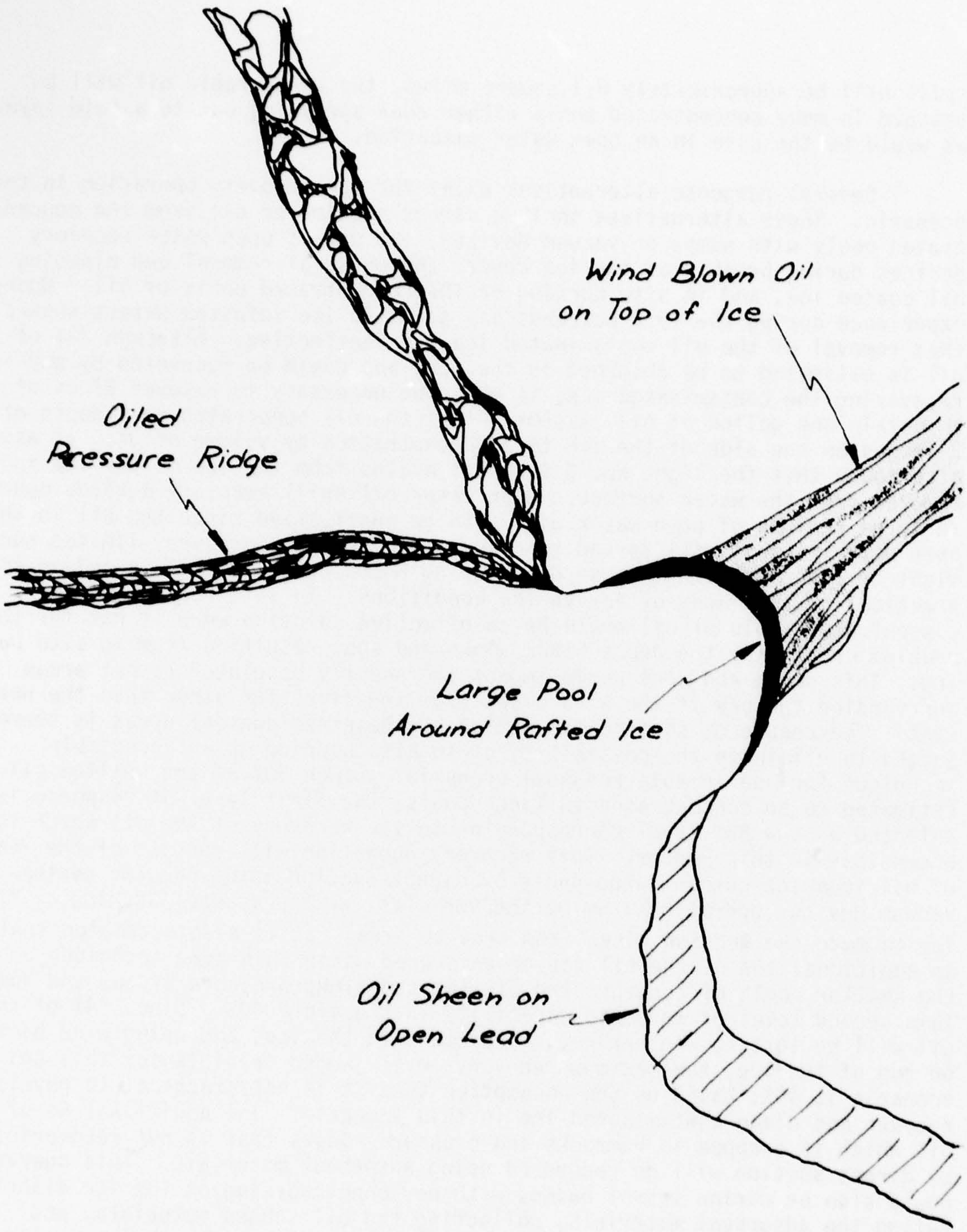


Figure 103. Conceptual Sketch of Oil Spill Behavior for the Northeastern Coast Scenario.

spill will be approximately 0.1 square miles, the recoverable oil will be trapped in many concentrated pools rather than spreading out to a thin layer as would be the case in an open water situation.

Several response alternatives exist for the recovery operation in this scenario. These alternatives include direct suction of oil from the concentrated pools with pumps or vacuum devices, the use of open water recovery devices during breakup of the ice cover, the physical removal and cleaning of oil coated ice, and in situ burning of the concentrated pools of oil. Operating experience during the 1977 Buzzards Bay spill in ice infested waters showed that removal of the oil contaminated ice was ineffective. Although 31% of the oil is estimated to be absorbed in the ice, and could be recovered by physically recovering the contaminated ice, it would be necessary to recover 27 cf of ice to obtain one gallon of oil, assuming that the oil penetrates to a depth of 2 inches on one side of the ice to a concentration by volume of 3%. It was also found that the light No. 2 fuel oil drains from the ice as the ice is removed from the water surface. Open water oil spill recovery devices operating in large regions of open water will also be ineffective since the oil in the open water regions will spread to a very thin sheen. Some very limited success might be expected with the use of sweeping booms, however, this is judged impractical in this area of active ice conditions. In situ burning of the concentrated pools of oil would be an effective solution were it not for the problem created by the dense black smoke and soot resulting from in situ burning. This smoke and soot would impact the heavily populated resort areas surrounding the bay if the wind blows from any direction other than the northeast. The chance of soot contamination of these residential areas is therefore judged to eliminate the possibility of in situ burning as an acceptable technique for use in this response scenario. Since 30% of the spilled oil is estimated to be concentrated in large pools, the first level of response is selected as the 30% level corresponding to the recovery of the oil which is accessible in this manner. This recovery operation will consist of the removal of oil from the concentrated pools by direct suction using pumping systems or vacuum devices operating from marine vehicles, with personnel working on the ice to move the suction hoses from area to area. It is also estimated that an additional 10% of the oil can be recovered using this same technique on the smaller pools of concentrated oil located along pressure ridges and hummocks. This second level of response capability is therefore 40%. Since 54% of the oil will be lost to weathering, entrainment in the ice, and being wind blown on top of the ice, the maximum recovery level judged feasible for this spill scenario is 46%, based on the assumption that it is not practical to physically recover and clean contaminated ice in this scenario. The additional 6% of the oil which is trapped in hummocks and pressure ridges that is not recoverable by direct suction will be recovered using adsorbent materials. This operation would also be marine vessel based, with personnel working on the ice distributing the adsorbent materials, collecting the oil soaked materials, and physically transferring the contaminated material in barrels to the marine vessel for transfer to shore.

Temporary storage must be accomplished through the use of marine vessels. Assuming a 50% recovery efficiency, 3,000 barrels, 4,000 barrels and 4,600 barrels of storage capacity will be required to achieve the 30, 40 and 46% response levels respectively. A tank barge would provide the necessary storage capacity, and in addition, serve as a work platform. Oil soaked adsorbent materials would be stored in open top containers on the deck of the barge.

Conventional means will be used for transfer of the oil from temporary storage to shoreside disposal sites. The liquid cargo will be transferred by conventional pumping systems, and the oil soaked absorbent material will be transferred using conventional bulk transfer equipment.

Final disposal of the recovered oil will be performed by shoreside oily waste processing facilities.

Personnel and equipment will be flown to a staging area located on the shore of Buzzards Bay. Since facilities aboard the vessels used in the spill response effort will be limited, most personnel will be housed and supported from shore. Special oil resistant low temperature clothing will be required for all members of the spill response team. A commercial barge and tug will be required, along with other small support vessels capable of operating in the existing ice conditions. Personnel will be shuttled between the spill response operations and the shoreside staging and support facilities aboard marine vessels and through the use of helicopters.

Weather forecasts will be required on an hourly basis. A spill behavior model and ice condition forecasts would be useful in planning the spill response effort. Emergency medical cases will be removed from the spill site to the nearest shoreside hospital by helicopter. All personnel working on the surface of the ice must have close helicopter support and must be equipped with emergency signalling equipment.

The preferred spill response techniques developed for the northern coastal regions spill scenario located at Buzzards Bay, Massachusetts are summarized in Table 87. Lists of equipment required for use in the spill response efforts are summarized in Tables 88 and 89.

TABLE 87. SUMMARY OF PREFERRED SPILL RESPONSE TECHNIQUES FOR THE NORTHERN COASTAL REGION SPILL SCENARIO

Function	30% Response Level	40% Response Level	46% Response Level
Detection	Visual by crew of tug	Same	Same
Surveillance	Initially by crew of tug, then light aircraft and helicopters	Same	Same
Containment	Limited natural	Same	Same
Recovery	Direct suction from large pools of concentrated oil	Same for large and small pools	Same plus use of adsorbents in hummocks and ridges
Storage	Tank barge	Same	Same
Transfer	Conventional pumps	Same	Same plus bulk transfer of oil soaked adsorbents
Disposal	Shore side oily waste processing plant	Same	Same plus incineration
Logistics	Commercial vessels and aircraft; shore side staging and support	Same	Same
Ancillary	Weather and ice forecasts, spill behavior model	Same	Same
Emergency Evacuation	Marine vessel and helicopter to shore side facilities	Same	Same

TABLE 88. EQUIPMENT REQUIRED TO ACHIEVE A 30% RESPONSE LEVEL FOR SCENARIO NO. 9

Subsystem	Item	No. Req'd.	Specifications	Weight/Volume
Surveillance	Helicopter	1		
	Surface marker	100	Buoyant, disposable	
Containment	None			
Recovery	Skimmer heads	4		
Storage	Tank barge	1	25,000 bbl. with pumps	
Transfer	Vacuum pumps	4	200 gpm; high suction head	
	Hoses	4	300' x 3" ea.	
Disposal	None			
Logistics	Tugs	2		
	C-130	1		
	Special Clothing	14 sets	Low temperature, oil resistant	
Ancillary	Weather forecasts	Daily		
	Communications Equipment			
Emergency Evacuation	Individual emergency beacons	14		

TABLE 89. VARIATIONS IN EQUIPMENT REQUIRED TO ACHIEVE THE 40% AND 46% RESPONSE LEVELS FOR SCENARIO NO. 9

Response Level	Surveillance	Containment	Recovery	Storage	Transfer	Disposal	Logistics	Ancillary	Emergency Evacuation
40%	ADD: Surface markers (200)		ADD: Skimmer heads (4)		ADD: Vacuum pumps (4) Hoses (4)		ADD: *Special clothing (13 sets)	ADD: *Spill behavior model	ADD: Individual emergency beacons (13)
46%	ADD: Surface markers (200)		ADD: Skimmer heads (4) Absorbent materials (1,400 lbs.)	ADD: Drums or cement troughs (350)	ADD: Vacuum pumps (4) Hoses (4) Sleds (5)		ADD: *Special clothing (23 sets)	ADD: *Spill behavior model	ADD: Individual emergency beacons (23)

* Research and development required.

EVALUATION OF ARCTIC SYSTEMS FOR SUBARCTIC APPLICATIONS

The investigation of subarctic spill scenarios, and the associated oil spill response scenarios, was concluded with an evaluation of the six alternative Coast Guard arctic pollution response systems for application to the three subarctic oil spill scenarios. The results of this investigation are summarized in this section of the report.

In comparing the arctic and subarctic oil spill scenarios it is readily apparent that there are major differences in three broad areas; the remoteness of the region, the environmental conditions surrounding the spill, and the type of oil spilled. The logistics problems associated with oil spill response for the subarctic scenarios are drastically less than those associated with the response for the arctic scenarios due to the relative proximity of facilities, equipment and manpower in the subarctic cases. Also of major significance is the fact that two of the subarctic oil spill scenarios are associated with the spillage of No. 6 residual fuel oil, while there are no residual fuel oil spills associated with the arctic scenarios. As a result, the behavior of the spilled oil, and the response approaches applicable are significantly different for the residual oil spills in comparison to either the crude oil spills or the light fuel oil spills where the volatility of the oil and the pour point are substantially higher. Finally, the three subarctic scenarios are representative of three distinct sets of subarctic environmental conditions, which in turn are distinct from the representative arctic environmental conditions associated with the arctic oil spill scenarios. As a result, different approaches toward oil spill response are required. The stationary brash ice conditions of the Great Lakes scenario are typical of the interconnecting waterways of the Great Lakes, the Upper Mississippi River, and the Illinois Waterway. The spillage of residual fuel oil in ice jams of brash ice requires the physical removal of the oil/ice mixture in order to recover the oil. The Hudson River oil spill scenario is representative of many coastal areas and bays where fast moving broken ice cover is found. This scenario is also representative of the ice conditions in inland rivers in the time period prior to the formation of stable ice cover. These conditions require an immediate response with oil spill recovery devices capable of operating in broken ice fields. The active ice conditions of the Buzzards Bay scenario are typical of all tidally influenced coastal waters during severe ice years, and are also representative of areas in the Great Lakes that experience wind blown ice floes. Here the primary response for a light fuel oil spill consists of searching for areas of oil concentration in the discontinuous ice features, and recovering oil from these concentrated pools. Therefore, while it might have initially been expected that there would be a substantial degree of commonality between the spill response equipment lists resulting from the arctic and subarctic analyses, the study indicates that there will be relatively limited commonality of equipment and techniques.

The equipment required for responding to the three subarctic oil spill scenarios are summarized in Tables 90 and 91. Three subarctic spill response systems were developed; one each for the minimum, intermediate and

TABLE 90. EQUIPMENT REQUIRED TO ACHIEVE THE MINIMUM 25% RESPONSE LEVEL FOR ALL THREE SUBARCTIC SCENARIOS - SYSTEM 7

Subsystem	Item	No. Req'd.	Specifications	Weight/Volume
Surveillance	Surface markers	200	Buoyant, disposable	
Containment	**Conventional high seas boom suitable for use in ice fields	5,000 ft.	4 ft.	6,250 lbs.
Recovery	Conventional oil recovery devices	1	Arctic boat or ZRV	14,000 lbs. ea.
	Oil Mop	1	Mark II-4H	
	Crane barge	1	Clamshell or dragline on 4,000 yd^3 barge	
	Skimmer heads	4		
	Vacuum trucks	4		
Storage	Tank barges	2	1-10,000 bbl, 1-15,000 bbl	
	Bladder tanks	2	1,000 gal. ea.	
Transfer	ADAPTS pumping system	1	1,000 gpm @ 32 ft. disch.	
	Portable pumps	2	200 gpm; 10 ft. suct; 150 ft disch., self-priming	
	Steam generators	2	4,000,000 BTUH ea.	5,700 lbs. ea.
	Hoses	4	300' x 3"	
Logistics	Tugs	3		
	C-130	1		
	Helicopter	1		
	Icebreaker	1		
	Special clothing	min.14 sets	Low temperature, oil resistant	
	Small boats	2	16'	

** Demonstration required.

TABLE 90. EQUIPMENT REQUIRED TO ACHIEVE THE MINIMUM 25% RESPONSE LEVEL FOR ALL THREE SUBARCTIC SCENARIOS - SYSTEM 7 (Continued)

Subsystem	Item	No. Req'd.	Specifications	Weight/Volume
Ancillary	Weather forecasts	Daily		
	River current predition model	1		
	Communications equipment			
Emergency Evacuation	Individual emergency beacons	14		

TABLE 91. VARIATIONS IN EQUIPMENT REQUIRED TO ACHIEVE THE INTERMEDIATE AND MAXIMUM RESPONSE LEVELS FOR ALL THREE SUBARCTIC SCENARIOS - SYSTEMS 8 and 9

Response Level	Surveillance	Containment	Recovery	Storage	Transfer	Disposal	Logistics	Ancillary	Emergency Evacuation
Inter-mediate (System 8)	ADD: Surface markers (100)	ADD: **Conventional high seas boom suitable for use in ice fields (10,000 ft.)	ADD: Conventional oil recovery devices (2) Oil Mops (3) Skimmer heads (4)	ADD: Bladder tanks (4)	ADD: Vacuum pumps (4) Hoses (4)		ADD: Tug (1) Special clothing (13 sets) Small boats (2)	ADD: *Spill behavior model	ADD: Individual emergency beacons (13)
Maximum (System 9)	ADD: Surface markers (100)	ADD: **Conventional high seas boom suitable for use in ice fields (10,000 ft.)	ADD: *Oil/ice vessel (1) Conventional oil recovery devices (2) Oil Mops (3) Skimmer heads (4) Absorbent materials (1,400 lbs.)	ADD: Bladder tanks (4) Cement troughs or drums (350)	ADD: Vacuum pumps (4) Hoses (4) Sleds (5)		ADD: Tugs (2) Special clothing (23 sets) Small boats (2)	ADD: *Spill behavior model	ADD: Individual emergency beacons (23)

* *Research and development required.*

** Demonstration required.

maximum spill response levels. These systems have been identified respectively as System 7, 8 and 9. These equipment lists correspond to the individual scenario equipment lists developed in the preceding section, with the exception that the special oil/ice recovery vessel required to achieve the 90% response level for the Great Lakes spill scenario and the 80% response level for the northern river spill scenario has been eliminated, since it was shown not to be cost effective in the arctic spill scenarios. The maximum response levels achievable based on the equipment lists in Table 91 therefore consist of the 50% response level for the Great Lakes scenario, the 45% response level for the northern rivers scenario, and the 46% response level for the northern coastal region scenario.

The inadequacies of the six arctic oil spill response systems when applied to the subarctic oil spill scenarios are summarized in Table 92. This table identifies the additional equipment required to extend the system capability to the subarctic applications for each of the six arctic systems by subsystem, scenario number, and response level. While some equipment is common between the arctic and subarctic scenarios, there is a substantial amount of additional equipment which is unique to the subarctic spill response effort. For example, the response conditions of the Great Lakes scenario require the physical recovery of oil intermixed in a rubble ice field. None of the arctic spill response scenarios required this type of recovery, which in the Great Lakes scenario is achieved through the use of a clam shell or dragline dredge and hopper barges. There are similarities between the subarctic Hudson River spill and the arctic Bristol Bay spill, with the ice conditions in the Hudson River scenario less severe. It has been judged that small boats can be safely operated in the Hudson, but not in connection with the Bristol Bay response effort. They are therefore a required addition to the arctic system for subarctic applications since they decrease the requirement for larger vessels and add to the flexibility of the spill response operations. The spill of heavy No. 6 fuel oil also requires the use of steam generating equipment to heat the oil to a temperature above its pour point. The conditions surrounding the spill, and the preferred spill response techniques associated with the arctic spills did not require the use of steam generating equipment for heating the oil during the response operation.

Table 93 is a summary of equipment contained in the six arctic pollution response systems which are not required in any of the subarctic scenarios. Since ice thicknesses in subarctic regions are rarely sufficient to permit the transit of heavy equipment and vehicles across the ice cover, equipment required for the spill response on thick level ice in the arctic scenarios is clearly not applicable to the subarctic scenarios. Included in this category are such items as large downhole drills, bulldozers, crew transport vehicles, tracked snow vehicles and graders. Other items which have been required for the arctic spill response effort could be applicable in the subarctic although they are not required in the preferred subarctic responses developed in this program. This equipment would include such things as chain saws, under ice markers, and diving equipment. Also, since all subarctic spills are in much closer proximity to onshore facilities, the surveillance, logistics and ancillary equipment requirements are far less extensive than they are for the

TABLE 92. INADEQUACIES OF ARCTIC RESPONSE SYSTEMS WHEN APPLIED TO THE SUBARCTIC OIL SPILL SCENARIOS

Arctic System	Subsystem	Additional Equipment Required for Subarctic Spills	Scenario No.	Response Level, %
2	Containment	2,600 ft Boom	8	25
		12,600 ft Boom	8	45, 80
	Recovery	1 Crane barge	7	25, 50
		1 Oil Mop	8	25
(Optimum)		4 Oil Mops	8	45, 80
		1 Oil/ice recovery vessel	7	90
		1 Oil/ice recovery vessel	8	80
		1,400 lbs. Adsorbent materials	9	46
	Storage	1 Hopper barge	7	90
		2 Bladder tanks	8	25
		6 Bladder tanks	8	45
		300 Cement troughs or drums	9	46
	Transfer	1 Steam generator	7	All
		2 Steam generators	8	All
		5 Sleds	9	46
		4 Vacuum trucks	9	30
		8 Vacuum trucks	9	40, 46
	Logistics	1 Small boat	8	25
		4 Small boats	8	45, 80
	Ancillary	1 Spill behavior model	8	All
		1 Spill behavior model	9	45, 46
1	Containment	2,600 ft Boom	8	25
		12,600 ft Boom	8	45, 80
	Recovery	1 Crane barge	7	25, 50
		1 Oil Mop	8	25
		4 Oil Mops	8	45, 80
		1 Oil/ice recovery vessel	7	90
		1 Oil/ice recovery vessel	7	80
		1,400 lbs, Adsorbent materials	9	46
	Storage	1 Hopper barge	7	90
		2 Bladder tanks	8	25
		6 Bladder tanks	8	45
		300 Cement troughs or drums	9	46

TABLE 92. INADEQUACIES OF ARCTIC RESPONSE SYSTEMS WHEN APPLIED TO THE SUBARCTIC OIL SPILL SCENARIOS (Continued)

Arctic System	Subsystem	Additional Equipment Required for Subarctic Spills	Scenario No.	Response Level, %
1	Transfer	1 Steam generator	7	All
		2 Steam generators	8	All
		5 Sleds	9	46
		4 Vacuum trucks	9	30
		8 Vacuum trucks	9	40, 46
	Logistics	1 Small boat	8	25
		4 Small boats	8	45, 80
	Ancillary	1 Spill behavior model	8	All
		1 Spill behavior model	9	45, 80
3	Containment	2,600 ft Boom	8	25
		12,600 ft Boom	8	45, 80
	Recovery	1 Crane barge	7	25, 50
		1 Oil Mop	8	25
		4 Oil Mops	8	45, 80
		1,400 lbs. Adsorbent materials	9	46
	Storage	1 Hopper barge	7	90
		350 Cement troughs or drums	9	46
	Transfer	1 Steam generator	7	All
		2 Steam generators	8	All
		4 Vacuum trucks	9	30
		8 Vacuum trucks	9	40, 46
	Logistics	1 Small boat	8	25
		4 Small boats	8	45, 80
4	Containment	2,600 ft Boom	8	25
		12,200 ft Boom	8	45, 80
	Recovery	1 Crane barge	7	25, 50
		1 Oil Mop	8	25
		4 Oil Mops	8	45, 80
		1,400 lbs. Adsorbent materials	9	46
		6 Skimmer heads	9	40, 46

TABLE 92. INADEQUACIES OF ARCTIC RESPONSE SYSTEMS WHEN APPLIED TO THE SUBARCTIC OIL SPILL SCENARIOS (Continued)

Arctic System	Subsystem	Additional Equipment Required for Subarctic Spills	Scenario No.	Response Level, %
	Storage	1 Hopper barge	7	90
		350 Cement troughs or drums	9	46
		2 Bladder tanks	8	25
		6 Bladder tanks	8	45, 80
	Transfer	1 Steam generator	7	All
		2 Steam generators	8	All
		5 Sleds	9	46
		4 Vacuum trucks	9	30
		8 Vacuum trucks	9	40, 46
	Logistics	1 Small boat	8	25
		4 Small boats	8	45, 80
5	Containment	2,600 ft Boom	8	25
		12,600 ft Boom	8	45, 80
	Recovery	1 Crane barge	7	25, 50
		1 Oil Mop	8	25
		4 Oil Mops	8	45, 80
		1,400 lbs. Adsorbent materials	9	46
		6 Skimmer heads	9	40, 46
	Storage	1 Hopper barge	7	90
		350 Cement troughs or drums	9	46
		3 Bladder tanks	8	45, 80
	Transfer	1 Steam generator	7	All
		2 Steam generators	8	All
		5 Sleds	8	46
		4 Vacuum trucks	9	30
		8 Vacuum trucks	9	40, 46
6	Containment	2,600 ft Boom	8	25
		12,600 ft Boom	8	45, 80
	Recovery	1 Crane barge	7	25, 50
		1 Oil Mop	8	25
		4 Oil Mops	8	45, 80
	Storage	1 Hopper barge	7	90
		3 Bladder tanks	8	45, 80
		310 Cement troughs or drums	9	46

TABLE 92. INADEQUACIES OF ARCTIC RESPONSE SYSTEMS WHEN APPLIED TO THE SUBARCTIC OIL SPILL SCENARIOS (Continued)

Arctic System	Subsystem	Additional Equipment Required for Subarctic Spills	Scenario No.	Response Level, %
6	Transfer	1 Steam generator	7	All
		2 Steam generators	8	All
		5 Sleds	9	46
		4 Vacuum trucks	9	30
		8 Vacuum trucks	9	40, 46

TABLE 93. ARCTIC SYSTEM EQUIPMENT NOT REQUIRED IN SUBARCTIC SCENARIOS

Arctic System	Surveillance	Recovery	Disposal	Logistics	Ancillary
2 (Optimum)	Fixed Wing Aircraft Electronic Devices Diving Equipment Under-Ice Markers Augers Chain Saws	Downhole Drill Means to Direct Oil Under Ice Into Holes Bulldozer	Open Flame Burner Incendiary Devices	Generators Light Plants Crew Transport Vehicle Graders Space Heaters Portable Water Pumps Portable Shelters	Radio Beacons
1	Fixed Wing Aircraft Electronic Devices Diving Equipment Under-Ice Markers Augers Chain Saws	Downhole Drill Bulldozer	Open Flame Burner Incendiary Devices	Generators Light Plants Crew Transport Vehicle Graders Space Heaters Portable Water Pumps Portable Shelters	Radio Beacons
3	Fixed Wing Aircraft Electronic Devices Diving Equipment Under Ice Markers Augers Chain Saws	Downhole Drill Means to Direct Oil Under Ice Into Holes Bulldozer	Open Flame Burner Incendiary Devices	Generators Light Plants Crew Transport Vehicle Graders Snow Tracked Vehicle Portable Water Pumps Portable Shelters Space Heaters	Radio Beacons

TABLE 93. ARCTIC SYSTEM EQUIPMENT NOT REQUIRED IN SUBARCTIC SCENARIOS (Continued)

Arctic System	Surveillance	Recovery	Disposal	Logistics	Ancillary
4	Fixed Wing Aircraft Electronic Devices Diving Equipment Under Ice Markers Augers Chain Saws	Downhole Drill Means to Direct Oil Under Ice Into Holes Bulldozer	Open Flame Burner Incendiary Devices	Generators Light Plants Crew Transport Vehicle Graders Space Heaters Portable Water Pumps Portable Shelters	Radio Beacons
5	Fixed Wing Aircraft Electronic Devices Augers Chain Saws Diving Equipment Under Ice Markers	Downhole Drill Means to Direct Oil Under Ice Into Holes Bulldozer	Open Flame Burner Incendiary Devices	Generators Light Plants Graders Space Heaters Portable Water Pumps Skycrane Helicopter Portable Shelters	Radio Beacons
6	Augers Chain Saws Diving Equipment Under Ice Markers Fixed Wing Aircraft Electronic Devices	Downhole Drill Bulldozer Means to Direct Oil Under Ice Into Holes	Incendiary Devices Open Flame Burner	Crew Transport Vehicle Graders Space Heaters Portable Water Fumps Skycrane Helicopter Light Plants Generators Portable Shelters	Radio Beacons

arctic. Equipment such as electronic surveillance devices, power generators, lighting plants, portable shelters, space heaters, and radio beacons are not as applicable to the subarctic spill response effort as they are to the arctic cases.

Table 94 is a summary of the equipment required to expand the optimum arctic oil spill response system to include capability for the minimum and intermediate response levels for the subarctic scenarios. Again, the special oil/ice recovery vessel required to achieve the 90% response level in the Great Lakes scenario and the 80% response level for the northern rivers scenario has not been included since it did not prove to be cost effective in the arctic scenarios. Subsystems of the optimum arctic spill response system that require no additional equipment for application to the subarctic oil spill scenarios are the surveillance, disposal, and emergency evacuation subsystems. The containment subsystem has required only minor modification to the extent that a greater quantity of oil boom is specified. Subsystems requiring significant modification include recovery, storage, transfer and ancillary. A crane barge, Oil Mop units, and adsorbent materials have been added to the recovery subsystem. A hopper barge, bladder tanks and drums have been added to the storage subsystem. Steam generators, vacuum trucks and sleds have been added to the transfer subsystem, small boats have been added for logistics, and an oil spill behavior model for use in the northern coastal region scenario has been added to the ancillary subsystem. Some of the subarctic equipment, such as the Oil Mop devices and adsorbent materials may also be useful in some arctic response efforts, however, the use of clam shell dredges and hopper barges would be impractical in several of the arctic scenarios due to the logistics problems associated with getting this equipment to the spill site. The equipment list of Table 94 therefore includes the equipment required for the optimum arctic spill response system, plus the equipment required to achieve a 45 to 50% response level for the three subarctic oil spill scenarios. While this equipment list corresponds to the preferred approaches developed for the arctic and subarctic oil spill response scenarios, it is again pointed out that the use of this equipment in the manner suggested in many cases must be demonstrated before the system can be considered to be an operational pollution response system. The research and development needs, including the requirements for demonstration programs, resulting from this work will be the subject of a separate report.

TABLE 94. ADDITIONS REQUIRED TO THE OPTIMUM ARCTIC OIL SPILL RESPONSE SYSTEM TO PROVIDE A 45 TO 50% RESPONSE TO THE SUBARCTIC SCENARIOS

Surveillance	Containment	Recovery	Storage	Transfer	Disposal	Logistics	Ancillary	Emergency Evacuation
	**Conventional high seas boom suitable for use in ice fields (12,600 ft.)	Crane barge (1) Oil Mops (4) Adsorbent materials (1,400 lbs.)	Cement troughs or drums (300) Bladder tanks (6-1,000 gal.) Hopper barge (1)	Steam generators (2) Sleds (5) Vacuum trucks (8)		Small boats (4)	*Spill behavior model	

* Research and development required.
** Demonstration required.

CONCLUSIONS

The major conclusions which can be drawn from this study are as follows:

1. The arctic and subarctic oil spill response scenarios developed in this program reveal that there could be a substantial degree of current capability for responding to arctic and subarctic oil spills in ice infested waters. This potential current capability results largely from the application of currently available hardware and equipment in novel ways. Therefore, while much of the equipment comprising the optimum arctic pollution response system is currently available, the techniques for applying the equipment to the spill response effort in ice infested waters are often new.

2. While some significant effort will have to be devoted to the research and development of new equipment for the optimum arctic pollution response system, the greatest portion of the research and development effort will be devoted towards the evaluation of equipment alternatives, and the demonstration of the proposed spill response techniques in both laboratory and field test programs.

3. Practical limits are placed on the degree of oil spill response capability which is achievable by the type of oil spilled and the environmental conditions surrounding the spill. These are the major factors which affect the loss of portions of the spilled oil due to natural processes, such as evaporation and dissolution into the water column, which, in turn, determines the amount of recoverable oil remaining at any particular time after the spill incident.

4. The presence of continuous and discontinuous ice features in the oil spill situation both hinders and helps the spill response effort. For spill response operations conducted in light ice conditions where the spill response effort closely parallels that for open water conditions, the presence of ice clearly hinders the spill response operation. In other situations where there is a substantial thickness of stable ice cover, the ice cover is helpful in that it can serve as a base of operations for heavy equipment used in the spill response effort. In addition, the ice provides a natural containability of oil in the surface relief of the under-surface of the ice.

5. Three distinctly different types of Alaskan spill response incorporating distinct operational approaches were identified in this study on the basis of the selected oil spill scenarios. The three types are summarized as follows:

Group I: Thick, stable, level ice. A release of oil beneath thick, stable, level ice results in a degree of spill containment in the rough or undulating under ice surface features. The thick ice prevents ready access by most marine vehicles, but also provides a working platform for heavy land-type construction vehicles.

The response effort is primarily concerned with gaining access to the oil trapped beneath the ice by working on the ice surface.

Group II: Dynamic, hummocky ice. A release of oil in a hummocky moving ice field requires a primarily marine vessel oriented response, but some operations may be possible on the ice surface. Depending on the ice field dynamics, the released oil at some point in time will be incorporated in discontinuous ice features, such as hummocks and pressure ridges, at which point recovery becomes extremely difficult, and is judged to require the use of a specialized vessel.

Group III: Open water or light ice conditions. This type of response is characterized by a generally open water spill behavior. Response efforts must be exclusively marine based and oriented toward the recovery of oil from the surface of water. The light ice conditions eliminate the possibility of ice-based response methods, and complicate the application of open water spill recovery techniques and equipment.

6. The cost effectiveness analysis performed for the arctic oil spill response scenarios revealed that, in general, the more cost effective response efforts tend toward the lower levels of response capability. The optimum arctic pollution response system provides the capability for achieving a 25% response level for four of the six scenarios, and a 50% response level for the remaining two scenarios.

7. The achievement of a very high 80% response level has been estimated to require the use of a special oil/ice recovery vessel in three of the six arctic spill scenarios representative of the Group II and III types of response, and two of the three subarctic spill scenarios. This special vessel, which does not currently exist, would have the capability to recover and clean oil contaminated ice pieces, while recovering the oil remaining on the open water once the ice pieces have been removed. Such a special purpose vessel was judged to be non cost effective based on the cost effectiveness study performed for the arctic cases.

8. The optimum arctic pollution response system incorporates both equipment which can be used in all three types of spill response, and equipment which is useful in only one type of spill response. Since the oil spill scenarios were selected to be representative of a range of environmental conditions and spill situations, there are unique conditions which require the application of unique equipment and techniques, rather than universal response equipment or techniques. The optimum arctic oil pollution response system is, therefore, basically a combination of several types of response system which takes advantage of equipment commonality where such commonality exists.

9. In the same manner that there is relatively limited commonality of equipment and technique throughout the response scenarios developed for the six arctic spill scenarios, there is relatively limited commonality of equipment and technique between the arctic spill response scenarios and the subarctic spill response scenarios, and, in fact, within the three subarctic spill response scenarios themselves. Therefore, the extension of the optimum arctic pollution response system to incorporate a subarctic spill response capability virtually results in the addition of a subarctic system to the optimum arctic system.

RECOMMENDATIONS

Based upon the projected development of Alaska's offshore petroleum resources, it is recommended that the U. S. Coast Guard proceed as planned towards developing a complete arctic pollution response system by early next decade. The next step of this process is to develop detailed research and development plans which will result in the availability of the optimum arctic pollution response system for use by the early 1980's. It is also recommended that the pollution response system for use in subarctic ice infested waters be developed as a separate system rather than incorporated into the arctic pollution response system. While there is some commonality of equipment in the two systems, there are also substantial differences which may result in the achievement of a more effective response capability through the development of two systems. In addition, it is judged that it would be desirable to store the subarctic system equipment in a more central location relative to the area of expected use on the Great Lakes, in the northern rivers, and in the northern coastal region. Considering the sub-arctic system to be a part of the arctic pollution response system implies that it would be stored and maintained in a ready condition in Alaska, most likely either in Anchorage or Kodiak. These locations may not be the preferred locations for storage of the subarctic response system.

REFERENCES

1. Swift, W.H., et al., "Geographical Analysis of Oil Spill Potential Associated with Alaskan Oil Production and Transportation System," CG-D-79-74, Department of Transportation, U.S. Coast Guard, Washington, D.C., February 1974.

2. Isakson, J.S., et al., "Comparison of Ecological Impacts of Postulated Oil Spills at Selected Alaskan Locations,"CG-D-155-75, 2 vols., Department of Transportation, U.S. Coast Guard, Washington, D.C., June 1975.

3. Milne, A.R. and B.D. Smiley, "Offshore Drilling for Oil in the Beaufort Sea, A Preliminary Environmental Assessment" (revised), Department of the Environment, Beaufort Sea Project, Victoria, B.C., January 1976.

4. University of Alaska, Arctic Project Office, Outer Continental Shelf Environmental Assessment Program, "Environmental Impacts of Outer Continental Shelf Development in Northern Alaska," Special Bulletin #15, Proceedings of a Synthesis Meeting of Outer Continental Shelf Environmental Assessment Program and Other Investigators Working in Northern Alaska, Barrow, Alaska, February 7-11, 1977.

5. Anonymous, "U.S. Oil, Gas Reserves Continue Steep Decline," *World Oil*, vol.184, No. 3, February 15, 1977, pp. 110-116.

6. Powers, R.B., Oil and Gas Resource Appraisal Group, U.S. Geological Survey, Denver, Colorado, Personal communication, September 1977.

7. BDM Corporation, "Report of the National Planning Conference in the Commercial Development of the Oceans," MA-GEN-900-77072, 2 vols., Energy Research and Development Administration, Washington, D.C., June 1976.

8. Potocsky, G.J., "Alaskan Area 15- and 30-Day Ice Forecasting Guide," Naval Oceanographic Office, Washington, D.C., February 1975.

9. Johnson, P.R. and C.W. Hartman, *Environmental Atlas of Alaska*, 2nd edition, University of Alaska, College, Alaska, January 1971.

10. U.S. Department of Commerce, "Tide Tables West Coast of North and South America 1975," Defense Mapping Agency, Hydrographic Center, 1974.

11. U.S. Geological Survey, Department of the Interior, "Index of Surface-Water Records to September 30, 1970 - Part 15-Alaska," Geological Survey Circular 665, U.S. Geological Survey, Washington, D.C., 1971.

12. Hamilton, D.R. and S.E. Seim, "Temperature, Salinity, and Density of the World's Seas: Bering Sea," Informal Report No. 68-80, Naval Oceanographic Office, Washington, D.C., September 1968.

13. Selkregg, L.L., compiler, *Alaska Regional Profiles*, vol. 1-5, State of Alaska, Office of the Governor, Juneau, Alaska, 1976.

14. National Oceanic and Atmospheric Administration, "Local Climatological Data, 1974, Barrow, Alaska," National Climatic Center, Asheville, North Carolina, 1974.

15. Kovacs, Austin, "Sea Ice Thickness Profiling and Under-Ice Entrapment," *Proceedings*, 1977 Offshore Technology Conference, Vol. 3, Houston, Texas, May 2-5, 1977.

16. Martin, Seelye, "The Seasonal Variation of Oil Entrainment in First Year Arctic Sea Ice: A Comparison of NORCOR/OCS Observations," prepared by the University of Washington, Department of Oceanography, Report Number 71, March 1977.

17. "Guidelines for the Use of Coast Guard Resources During Pollution Removal Operations," Commandant Instruction 16465.2A, U.S. Coast Guard, November 1976.

18. Department of the Army, Corps of Engineers, "Waterborne Commerce in the United States," 1976.

19. Rondy, Donald R., "Great Lakes Ice Atlas," NOAA TM NOS LSCDR (Lake Survey Center), September 1971.

20. Baum, J.U., et al., "Climatological and Environmental Factors that Influence Survival on the Great Lakes," NTIS AD-768-678, June 15, 1973.

21. NOAA, "United States Great Lakes Pilot," April 1977.

22. Philips, D.W., and J.W.A. McCulloch, "The Climate of the Great Lakes Basin," Environment Canada, Toronto 1972.

23. NOAA, "Local Climatological Data - Annual Summary with Comparative Data," Environmental Service, National Climatic Center, Asheville, North Carolina.

24. Ashton, G.D., "Evaluation of Ice Management Problems Associated with Operation of a Mechanical Ice Cutter on the Mississippi River," CRREL Special Report No. 214, October 1974.

25. U.S. Coast Guard, "Major Oil Spill Information System Listing," Transportation Systems Command, Cambridge, Massachusetts, November 1977.

26. NOAA, "Tidal Current Tables 1977, Atlantic Coast of North America," National Ocean Survey, Rockville, Maryland, 1976.